AD-A033 658 PRC INFORMATION SCIENCES CO ROME N Y F/G 15/3
SPACE SURVEILLANCE SOFTWARE SUPPORT. VOLUME 1, PART 1, BOOK 3. --ETC(U)
OCT 76 P R CONTI F30602-75-C-0167
UNCLASSIFIED RADC-TR-76-261-VOL-1-PT-1- NL

1 OF 1
ADA033658

END
DATE
FILMED
2 - 77

RADC-TR-76-261, Volume I, Part 1, Book 3
Final Technical Report
October 1976

SPACE SURVEILLANCE SOFTWARE SUPPORT
Computer Program Documentation

PRC Information Sciences Company

ROME AIR DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
GRIFFISS AIR FORCE BASE, NEW YORK 13441

This report contains a large percentage of machine-produced copy which is not of the highest printing quality but because of economical consideration, it was determined in the best interest of the government that they be used in this publication.

This report has been reviewed by the RADC Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations

This report has been reviewed and approved for publication.

APPROVED: John C. Cleary

JOHN C. CLEARY
Project Engineer

APPROVED: Rudolf C. Paltauf

RUDOLF C. PALTAUF, Lt Col, USAF
Chief, Surveillance Division

FOR THE COMMANDER: John P. Huss

JOHN P. HUSS
Acting Chief, Plans Office

Do not return this copy. Retain or destroy.

Volume 1, Part 1, Book 3.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: RADC-TR-76-261, Vol I, Pt 1, Book 3 — 2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): SPACE SURVEILLANCE SOFTWARE SUPPORT. Computer Program Documentation.	5. TYPE OF REPORT & PERIOD COVERED: Final Technical Report. April 1975 - July 1976.
	6. PERFORMING ORG. REPORT NUMBER: N/A
7. AUTHOR(s): P. Richard Conti	8. CONTRACT OR GRANT NUMBER(s): F30602-75-C-0167
9. PERFORMING ORGANIZATION NAME AND ADDRESS: PRC Information Sciences Company, 8606 Turin Road, Rome NY 13440	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62702F, 65121205
11. CONTROLLING OFFICE NAME AND ADDRESS: Rome Air Development Center (OCSA), Griffiss AFB NY 13441	12. REPORT DATE: October 1976
	13. NUMBER OF PAGES: 83
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Same	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

RADC Project Engineer:
John C. Cleary (OCSA)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Trajectory Software
Radar Cross Section
Orbit
Classifiers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this effort was to modify the RADC trajectory program, orbit program and various radar cross section programs were modified to run on the RADC HIS 6180 computer under the GCOS system software. The RADC trajectory program was modified to include the capability of processing multiple (20) radar sites and multiple (20) targets in the program so that various radar parameters could be determined. This type of information is essential in performing radar coverage analyses for systems such as COBRA TALON, SEEK SAIL, COBRA DANE and COBRA JUDY. This portion of the effort is documented in Vol I.

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

409 280
6pg

Line 20 (continued) Vol II documents a procedure for punching cards in ASCII format and reading the data onto a HP cassette for subsequent plotting with an HP9820 calculator system.

Vol III documents some Radar Signature and Radar Scattering computer programs. A three diminsional plot program contained in this volume has been incorporated into the Interactive Radar Simulator for plotting three dimensional antenna patterns and cross section aspect angle histories.

ABSTRACT

The objective of the effort documented herein was to provide computer programming support for Space Surveillance system analysis. The two primary tasks of the effort were to complete the modification of the RADC Trajectory Program and to modify various radar cross-section and other computer programs so that they could be accessed from the interactive system for the RADC Radar Simulator. The documentation is organized as follows:

Volume I, Part 1, Book 1 - Project Summary and Computer Program Documentation (Chapters I-III of Volume I, Part 1)

Volume I, Part 1, Book 2 - Computer Program Documentation (Chapter IV)

Volume I, Part 1, Book 3 - Computer Program Documentation (Chapters V-VI and Appendices A-E)

Volume I, Part 2 - RADC Trajectory Program - Numerical/Analytical Data

Volume II - Generalized Data Entry and Plot Program

Volume III - Radar Signature and Radar Scattering Principles Investigation Software

V. Description of Auxiliary Computer Programs

Several computer programs were developed to perform the auxiliary function of punching out data files so that plots could be generated on the Hewlett-Packard 9820A calculator/plotter. Radar coverage parameters were computed and placed on a file by any one of three trajectory-type programs, the RADC Trajectory Program, the Cobra Talon Trajectory Program, or the Orbit Prediction Program. The data on file would then be accessed by the appropriate auxiliary program and punched onto cards to be read by the Generalized Data Entry and Plot Program (described in Volume II) on the HP 9820A. A listing of the source code, a sample job stream, and sample output for each of the auxiliary programs follow. The sample output represents a portion of the printout from the execution of each program. The first set of listing, job stream, and output is given for the program to punch out the RADC Trajectory Program plot file, the second set is for the Cobra Talon punch program, and the third for the Orbit Prediction punch program.

```
CPUNCH  PUNCH DATA FROM TRAJECTORY PROGRAM
C
      DIMENSION BUFF(5000),RANGE(2000)
    LOGICAL IPLOT2,EOF,EOF10,SWTCH2,SWITCH
       NAMELIST/NAM1/TIMINC,NPLOT,NSITE,NTRAJ
      REWIND 10
       READ(5,NAM1)
       WRITE(6,NAM1)
       INCTIM=TIMINC/0.10+1.0E-5
       DO 200 ITRAJ=1,NTRAJ
       IF(ITRAJ.EQ.2)GO TO 200
       DO 120 ISITE=1,NSITE
  10  READ(10)TIME3,IPLOT2,IO2,EOF
       KK = 1
    IF(EOF)GO TO 120
    DO 70 IPLOT=1,NPLOT
    IBACK=0
    RMAX=-1.0E+20
    RMIN=1.0E+20
     NPTS=0
    I=0
    SWITCH=.FALSE.
  20 READ(10)NREC3,NREC4,NREC5,EOF10,SWTCH2
    IBACK=IBACK+1
     IF(EOF10) GO TO 40
     NDATA=NREC3*IO2
     INCBUF=INCTIM*IO2
     READ(10)(BUFF(J),J=1,NDATA)
    IBACK=IBACK+1
    K=KK
    IF(SWITCH)K=II
  30 I=I+1
     NPTS =NPTS+1
     RANGE(I)=BUFF(K)
     R=RANGE(I)
     IF(R.GT.RMAX)RMAX=R
     IF(R.LT.RMIN)RMIN=R
     K=K+INCBUF
     IF(K.LE.NDATA)GO TO 30
    IF(TIMINC.LT.0.10+1.0E-5)GO TO 20
    SWITCH=.TRUE.
    II=NDATA-(K-INCBUF)
    II=INCBUF-II
    IF(II.EQ.0)II=INCBUF
     GO TO 20
    40 WRITE(6,110)ITRAJ,ISITE
   110 FORMAT(///2X,"TRAJECTORY NUMBER",I6,5X,"RADAR SITE NUMBER",I6)
     WRITE(6,90)IPLOT
  90 FORMAT(///2X,"RADAR PARAMETER",I6//9X,"MAXIMUM",7X,
 &   "MINIMUM",4X,"INIT. TIME",6X,"TIME INC.",3X,"NO. OF PTS.")
    WRITE(6,50)RMAX,RMIN,TIME3,TIMINC,NPTS
     50 FORMAT(//2X,4E14.5,I6)
```

```
      PUNCH DATA FROM TRAJECTORY PROGRAM                                    LAI

      PUNCH 50,RMAX,RMIN,TIME3,TIMINC,NPTS
      WRITE(6,100)IPLOT
  100 FORMAT(X/2X,"DATA FOR PARAMETER",I6//)
      WRITE(6,60)(RANGE(I),I=1,NPTS)
   60 FORMAT(2X,5E14.5)
      PUNCH 60,(RANGE(I),I=1,NPTS)
      IF (IPLOT.EQ.NPLOT)GO TO 70
     DO 80 IB=1,IBACK
   80 BACKSPACE 10
     KK=KK+1
   70 CONTINUE
      GO TO 10
  120 CONTINUE
  200 CONTINUE
      STOP
      END
```

```
10$:IDENT:CLE ARY,CØNTI       ,65121104RADC,DSSR
20$:ØPTIØN :FØRTRAN
30$:SELECT:CLE ARY/ØPUNCHC
4000$:EXEC UTE
4005$:LIMITS :05,20K,,12000
4010$:PRMF L:10,R/W,L,CLEARY/DSTØRB
4020$:DATA:0 5
4030 $NAMI  TIMINC=0.1,NPLØT=6,NSITE=2,NTRAJ=1 $
5000$:ENDJØ B
5010***EØF
```

Sample Job Stream for Program to Punch Out
RADC Trajectory Program Plot File

SNUMB = 3820T, ACTIVITY # = 01, REPORT CODE = 06, RECORD COUNT = 000683

```
NAMELIST    NAM1
TIMINC=   0.10000000E 01,
NPLOT =           6,   NSITE =          2,   NTRAJ =           1,
$ END
```

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 1

RADAR PARAMETER 1

MAXIMUM	MINIMUM	INIT. TIME	TIME INC.	NO. OF PTS.
0.17226E 05	.83019E 04	0.47500E 02	0.10000E 01	96

DATA FOR PARAMETER 1

0.83019E 04	0.84045E 04	0.85076E 04	0.86112E 04	0.87152E 04
0.88196E 04	.89244E 04	0.90293E 04	0.91345E 04	0.92399E 04
0.93454E 04	0.94509E 04	0.95566E 04	0.96622E 04	0.97678E 04
0.98734E 04	.99789E 04	0.10084E 05	0.10190E 05	0.10295E 05
0.10400E 05	0.10504E 05	0.10609E 05	0.10713E 05	0.10817E 05
0.10921E 05	.11025E 05	0.11128E 05	0.11231E 05	0.11334E 05
0.11436E 05	0.11538E 05	0.11640E 05	0.11741E 05	0.11842E 05
0.11943E 05	.12043E 05	0.12143E 05	0.12242E 05	0.12341E 05
0.12440E 05	0.12538E 05	0.12636E 05	0.12734E 05	0.12831E 05
0.12928E 05	.13024E 05	0.13120E 05	0.13216E 05	0.13311E 05
0.13406E 05	0.13500E 05	0.13594E 05	0.13687E 05	0.13780E 05
0.13873E 05	.13965E 05	0.14057E 05	0.14148E 05	0.14239E 05
0.14329E 05	0.14419E 05	0.14509E 05	0.14598E 05	0.14687E 05
0.14775E 05	.14863E 05	0.14950E 05	0.15037E 05	0.15124E 05
0.15210E 05	0.15296E 05	0.15381E 05	0.15466E 05	0.15550E 05
0.15634E 05	.15718E 05	0.15801E 05	0.15884E 05	0.15966E 05
0.16048E 05	0.16130E 05	0.16211E 05	0.16291E 05	0.16372E 05
0.16451E 05	0.16531E 05	0.16610E 05	0.16688E 05	0.16766E 05
0.16844E 05	0.16921E 05	0.16998E 05	0.17075E 05	0.17151E 05
0.17226E 05				

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 1

RADAR PARAMETER 2

MAXIMUM	MINIMUM	INIT. TIME	TIME INC.	NO. OF PTS.
0.10704E 05	.76446E 04	0.47500E 02	0.10000E 01	96

DATA FOR PARAMETER 2

0.10361E 05	0.10422E 05	0.10475E 05	0.10522E 05	0.10562E 05
0.10596E 05	0.10626E 05	0.10650E 05	0.10669E 05	0.10683E 05
0.10694E 05	0.107[illegible]1E 05	0.10704E 05	0.10704E 05	0.10700E 05
0.10694E 05	0.10665E 05	0.10673E 05	0.10659E 05	0.10643E 05
0.10625E 05	0.106[illegible]4E 05	0.10582E 05	0.10559E 05	0.10534E 05
0.10507E 05	0.10479E 05	0.10450E 05	0.10419E 05	0.10387E 05
0.10355E 05	0.10321E 05	0.10287E 05	0.10252E 05	0.10216E 05
0.10179E 05	0.10142E 05	0.10104E 05	0.10066E 05	0.10027E 05
0.99873E 04	0.99474E 04	0.99072E 04	0.98665E 04	0.98256E 04
0.97843E 04	0.97428E 04	0.97010E 04	0.96590E 04	0.96168E 04
0.95743E 04	0.95317E 04	0.94890E 04	0.94461E 04	0.94031E 04
0.93600E 04	0.93168E 04	0.92735E 04	0.92302E 04	0.91868E 04
0.91434E 04	0.90999E 04	0.90565E 04	0.90130E 04	0.89695E 04
0.89260E 04	0.88825E 04	0.88390E 04	0.87955E 04	0.87521E 04
0.87087E 04	0.86654E 04	0.86220E 04	0.85788E 04	0.85356E 04
0.84924E 04	0.84493E 04	0.84063E 04	0.83633E 04	0.83204E 04
0.82775E 04	0.82348E 04	0.81921E 04	0.81495E 04	0.81070E 04
0.80645E 04	0.80221E 04	0.79798E 04	0.79376E 04	0.78955E 04
0.78535E 04	0.78115E 04	0.77697E 04	0.77279E 04	0.76862E 04
0.76446E 04				

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 1

RADAR PARAMETER 3

MAXIMUM	MINIMUM	INIT. TIME	TIME INC.	NO. OF PTS.
0.96106E 01	0.20147E 01	0.47500E 02	0.10000E 01	96

DATA FOR PARAMETER 3

0.20147E 01	0.256[illegible]6E 01	0.30777E 01	0.35672E 01	0.40301E 01
0.44675E 01	0.48804E 01	0.52699E 01	0.56369E 01	0.59822E 01
0.63069E 01	0.66116E 01	0.68973E 01	0.71646E 01	0.74144E 01
0.76472E 01	0.78639E 01	0.80649E 01	0.82511E 01	0.84228E 01
0.85808E 01	0.87255E 01	0.88575E 01	0.89772E 01	0.90851E 01
0.91817E 01	0.92674E 01	0.93426E 01	0.94077E 01	0.94631E 01
0.95091E 01	0.95461E 01	0.95745E 01	0.95945E 01	0.96064E 01
0.96106E 01	0.96073E 01	0.95968E 01	0.95793E 01	0.95551E 01
0.95244E 01	0.94875E 01	0.94446E 01	0.93958E 01	0.93414E 01
0.92815E 01	0.92164E 01	0.91462E 01	0.90711E 01	0.89913E 01
0.89069E 01	0.88181E 01	0.87249E 01	0.86277E 01	0.85264E 01
0.84212E 01	0.83123E 01	0.81997E 01	0.80836E 01	0.79641E 01
0.78413E 01	0.77152E 01	0.75861E 01	0.74540E 01	0.73189E 01
0.71810E 01	0.70404E 01	0.68971E 01	0.67513E 01	0.66029E 01
0.64521E 01	0.62990E 01	0.61435E 01	0.59859E 01	0.58261E 01
0.56642E 01	0.55003E 01	0.53343E 01	0.51665E 01	0.49969E 01
0.48254E 01	0.46521E 01	0.44772E 01	0.43006E 01	0.41223E 01
0.39425E 01	0.37612E 01	0.35784E 01	0.33942E 01	0.32085E 01
0.30215E 01	0.28331E 01	0.26435E 01	0.24526E 01	0.22605E 01

0.20672E 01

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 1

RADAR PARAMETER 4

MAXIMUM	MINIMUM	INIT. TIME	TIME INC.	NO. OF PTS.
0.93452E-02	-0.32316E-02	0.47500E 02	0.10000E 01	96

DATA FOR PARAMETER 4

0.93452E-02	0.88552E-02	0.83847E-02	0.79330E-02	0.74995E-02
0.70835E-02	0.66843E-02	0.63012E-02	0.59337E-02	0.55810E-02
0.52426E-02	0.49178E-02	0.46061E-02	0.43069E-02	0.40198E-02
0.37440E-02	0.34793E-02	0.32250E-02	0.29808E-02	0.27462E-02
0.25208E-02	0.23[illegible]41E-02	0.20958E-02	0.18956E-02	0.17030E-02
0.15178E-02	0.13396E-02	0.11682E-02	0.10032E-02	0.84431E-03
0.69134E-03	0.544[illegible]2E-03	0.40211E-03	0.26537E-03	0.13359E-03
0.65594E-05	-0.11592E-03	-0.23403E-03	-0.34796E-03	-0.45787E-03
-0.56394E-03	-0.666[illegible]2E-03	-0.76515E-03	-0.86059E-03	-0.95276E-03
-0.10418E-02	-0.11278E-02	-0.12110E-02	-0.12913E-02	-0.13690E-02
-0.14441E-02	-0.151[illegible]8E-02	-0.15871E-02	-0.16551E-02	-0.17209E-02
-0.17846E-02	-0.18462E-02	-0.19059E-02	-0.19637E-02	-0.20197E-02
-0.20740E-02	-0.21256E-02	-0.21775E-02	-0.22269E-02	-0.22747E-02
-0.23211E-02	-0.23661E-02	-0.24097E-02	-0.24521E-02	-0.24931E-02
-0.25330E-02	-0.25717E-02	-0.26092E-02	-0.26456E-02	-0.26810E-02
-0.27154E-02	-0.27487E-02	-0.27811E-02	-0.28126E-02	-0.28432E-02
-0.28729E-02	-0.29[illegible]18E-02	-0.29298E-02	-0.29571E-02	-0.29836E-02
-0.30094E-02	-0.30345E-02	-0.30589E-02	-0.30826E-02	-0.31057E-02
-0.31281E-02	-0.315[illegible]0E-02	-0.31712E-02	-0.31919E-02	-0.32120E-02
-0.32316E-02				

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 1

RADAR PARAMETER 5

MAXIMUM	MINIMUM	INIT. TIME	TIME INC.	NO. OF PTS.
0.32993E 03	0.29335E 03	0.47500E 02	0.10000E 01	96

DATA FOR PARAMETER 5

0.32993E 03	0.32913E 03	0.32834E 03	0.32756E 03	0.32680E 03
0.32606E 03	0.32533E 03	0.32462E 03	0.32392E 03	0.32323E 03

0.32256E 03	0.32190E 03	0.32125E 03	0.32061E 03	0.31999E 03
0.31938E 03	0.31878E 03	0.31819E 03	0.31761E 03	0.31704E 03
0.31648E 03	0.31594E 03	0.31540E 03	0.31487E 03	0.31436E 03
0.31385E 03	0.31335E 03	0.31286E 03	0.31239E 03	0.31191E 03
0.31145E 03	0.31099E 03	0.31054E 03	0.31010E 03	0.30967E 03
0.30925E 03	0.30883E 03	0.30842E 03	0.30802E 03	0.30763E 03
0.30724E 03	0.30686E 03	0.30648E 03	0.30611E 03	0.30575E 03
0.30539E 03	0.30504E 03	0.30470E 03	0.30436E 03	0.30403E 03
0.30370E 03	0.30338E 03	0.30307E 03	0.30276E 03	0.30245E 03
0.30215E 03	0.30185E 03	0.30156E 03	0.30128E 03	0.30100E 03
0.30072E 03	0.30045E 03	0.30018E 03	0.29992E 03	0.29966E 03
0.29940E 03	0.29915E 03	0.29890E 03	0.29866E 03	0.29842E 03
0.29819E 03	0.29795E 03	0.29773E 03	0.29750E 03	0.29728E 03
0.29706E 03	0.29685E 03	0.29664E 03	0.29643E 03	0.29623E 03
0.29603E 03	0.29583E 03	0.29563E 03	0.29544E 03	0.29525E 03
0.29507E 03	0.29488E 03	0.29470E 03	0.29452E 03	0.29435E 03
0.29418E 03	0.29401E 03	0.29384E 03	0.29367E 03	0.29351E 03
0.29335E 03				

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 1

RADAR PARAMETER 6

MAXIMUM	MINIMUM	INIT. TIME	TIME INC.	NO. OF PTS.
-0.26504E-02	-0.13576E-01	0.47500E 02	0.10000E 01	96

DATA FOR PARAMETER 6

-0.13576E-01	-0.13300E-01	-0.13031E-01	-0.12770E-01	-0.12515E-01
-0.12267E-01	-0.12026E-01	-0.11791E-01	-0.11561E-01	-0.11337E-01
-0.11119E-01	-0.10906E-01	-0.10698E-01	-0.10494E-01	-0.10296E-01
-0.10102E-01	-0.99122E-02	-0.97268E-02	-0.95457E-02	-0.93685E-02
-0.91953E-02	-0.90259E-02	-0.88602E-02	-0.86981E-02	-0.85395E-02
-0.83843E-02	-0.82324E-02	-0.80838E-02	-0.79384E-02	-0.77960E-02
-0.76566E-02	-0.75202E-02	-0.73866E-02	-0.72559E-02	-0.71278E-02
-0.70024E-02	-0.68796E-02	-0.67593E-02	-0.66415E-02	-0.65261E-02
-0.64131E-02	-0.63024E-02	-0.61939E-02	-0.60876E-02	-0.59835E-02
-0.58815E-02	-0.57815E-02	-0.56835E-02	-0.55875E-02	-0.54934E-02
-0.54012E-02	-0.53108E-02	-0.52222E-02	-0.51353E-02	-0.50502E-02
-0.49667E-02	-0.48848E-02	-0.48045E-02	-0.47258E-02	-0.46486E-02
-0.45729E-02	-0.44987E-02	-0.44259E-02	-0.43545E-02	-0.42844E-02
-0.42157E-02	-0.41483E-02	-0.40821E-02	-0.40172E-02	-0.39535E-02
-0.38910E-02	-0.38297E-02	-0.37695E-02	-0.37105E-02	-0.36525E-02
-0.35956E-02	-0.35397E-02	-0.34849E-02	-0.34311E-02	-0.33782E-02
-0.33263E-02	-0.32754E-02	-0.32253E-02	-0.31762E-02	-0.31279E-02
-0.30806E-02	-0.30340E-02	-0.29883E-02	-0.29434E-02	-0.28993E-02
-0.28560E-02	-0.28134E-02	-0.27716E-02	-0.27305E-02	-0.26901E-02
-0.26504E-02				

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 2

RADAR PARAMETER 1

MAXIMUM	MINIMUM	INIT. TIME	TIME INC.	NO. OF PTS.
0.84203E 04	.203 8E 04	0.94000E 01	0.10000E 01	40

DATA FOR PARAMETER 1

0.20308E 04	0.20790E 04	0.21599E 04	0.22684E 04	0.23992E 04
0.25476E 04	.27[illegible]93E 04	0.28809E 04	0.30598E 04	0.32438E 04
0.34311E 04	0.362[illegible]6E 04	0.38112E 04	0.40021E 04	0.41929E 04
0.43829E 04	.457[illegible]0E 04	0.47597E 04	0.49459E 04	0.51305E 04
0.53132E 04	0.549[illegible]2E 04	0.56732E 04	0.58503E 04	0.60253E 04
0.61984E 04	.63695E 04	0.65387E 04	0.67058E 04	0.68710E 04
0.70342E 04	0.71955E 04	0.73550E 04	0.75125E 04	0.76682E 04
0.78221E 04	.797[illegible]3E 04	0.81246E 04	0.82733E 04	0.84203E 04

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 2

RADAR PARAMETER 2

MAXIMUM	MINIMUM	INIT. TIME	TIME INC.	NO. OF PTS.
0.19348E 05	.30762E 04	0.94000E 01	0.10000E 01	40

DATA FOR PARAMETER 2

0.30762E 04	0.661[illegible]3E 04	0.96827E 04	0.12212E 05	0.14223E 05
0.15775E 05	.169[illegible]3E 05	0.17801E 05	0.18414E 05	0.18837E 05
0.19111E 05	0.19272E 05	0.19344E 05	0.19348E 05	0.19300E 05
0.19212E 05	.19[illegible]2E 05	0.18949E 05	0.18788E 05	0.18614E 05
0.18430E 05	0.182[illegible]8E 05	0.18042E 05	0.17842E 05	0.17641E 05
0.17439E 05	.172[illegible]7E 05	0.17036E 05	0.16837E 05	0.16639E 05
0.16444E 05	0.162[illegible]1E 05	0.16060E 05	0.15872E 05	0.15688E 05
0.15506E 05	.153[illegible]6E 05	0.15150E 05	0.14977E 05	0.14807E 05

TRAJECTORY NUMBER 1 RADAR SITE NUMBER 2

RADAR PARAMETER 3

```
      C        PUNCH RADAR DATA FROM COBRA TALON TRAJECTORY PROGRAM
      C
               DOUBLE PRECISION ARRAY(20)
              *,TIME1
               DIMENSION R(2000),RDOT(2000),A(2000),ADOT(2000),E(2000),
              *EDOT(2000)
               REWIND 2
               I=1
               RMAX=-1.0E+20
               RMIN=1.0E+20
               RDMAX=RMAX
               RDMIN=RMIN
               AMAX=RMAX
               AMIN=RMIN
               ADMAX=RMAX
               ADMIN=RMIN
               EMAX=RMAX
               EMIN=RMIN
               EDMAX=RMAX
               EDMIN=RMIN
               READ(2)TIME1,(ARRAY(J),J=2,20)
               TIME=TIME1
               IF(I.EQ.1)GO TO 5
            10 READ(2,END=50)ARRAY
             5 R(I)=ARRAY(2)
               RDOT(I)=ARRAY(3)
               A(I)=ARRAY(5)
               ADOT(I)=ARRAY(6)
               E(I)=ARRAY(8)
               EDOT(I)=ARRAY(9)
               IF(R(I).GT.RMAX)RMAX=R(I)
               IF(R(I).LT.RMIN)RMIN=R(I)
               IF(RDOT(I).GT.RDMAX)RDMAX=RDOT(I)
               IF(RDOT(I).LT.RDMIN)RDMIN=RDOT(I)
               IF(A(I).GT.AMAX)AMAX=A(I)
               IF(A(I).LT.AMIN)AMIN=A(I)
               IF(ADOT(I).LT.ADMIN)ADMIN=ADOT(I)
               IF(ADOT(I).GT.ADMAX)ADMAX=ADOT(I)
               IF(E(I).GT.EMAX)EMAX=E(I)
               IF(E(I).LT.EMIN)EMIN=E(I)
               IF(EDOT(I).GT.EDMAX)EDMAX=EDOT(I)
               IF(EDOT(I).LT.EDMIN)EDMIN=EDOT(I)
               IMAX=I
               I=I+1
               GO TO 10
            50 CONTINUE
               WRITE(6,20)RMAX,RMIN,TIME,0.1,IMAX
            20 FORMAT(//2X,4E14.5,I6//)
               WRITE(6,30)(R(J),J=1,IMAX)
            30 FORMAT(2X,5E14.5)
               PUNCH 20,RMAX,RMIN,TIME,0.1,IMAX
               PUNCH 30,(R(J),J=1,IMAX)
```

```
      WRITE(6,20)RDMAX,RDMIN,TIME,0.1,IMAX
      WRITE(6,30)(RDOT(I),I=1,IMAX)
      PUNCH 20,RDMAX,RDMIN,TIME,0.1,IMAX
      PUNCH 30,(RDOT(J),J=1,IMAX)
      WRITE(6,20)AMAX,AMIN,TIME,0.1,IMAX
      WRITE(6,30)(A(J),J=1,IMAX)
      PUNCH 20,AMAX,AMIN,TIME,0.1,IMAX
      PUNCH 30,(A(J),J=1,IMAX)
      WRITE(6,20)ADMAX,ADMIN,TIME,0.1,IMAX
      WRITE(6,30)(ADOT(J),J=1,IMAX)
      PUNCH 20,ADMAX,ADMIN,TIME,0.1,IMAX
      PUNCH 30,(ADOT(J),J=1,IMAX)
      WRITE(6,20)EMAX,EMIN,TIME,0.1,IMAX
      WRITE(6,30)(E(J),J=1,IMAX)
      PUNCH 20,EMAX,EMIN,TIME,0.1,IMAX
      PUNCH 30,(E(J),J=1,IMAX)
      WRITE(6,20)EDMAX,EDMIN,TIME,0.1,IMAX
      WRITE(6,30)(EDOT(J),J=1,IMAX)
      PUNCH 20,EDMAX,EDMIN,TIME,0.1,IMAX
      PUNCH 30,(EDOT(J),J=1,IMAX)
      STOP
      END
```

```
10$:IDENT:CLEARY,CØNTI     ,o5121104RADC
20$:ØPTIØN:FØRTRAN
30$:SELECT:CLEARY/ØCTPNCHC
40$:EXECUTE
42$:LIMITS:05,30K,,12000
45$:PRMFL:02,R/W,L,CLEARY/STØRE1
50$:ENDJØB
60***EØF
```

Sample Job Stream for Program to Punch Out
Cobra Talon Plot File

SNUMB = 7647T, ACTIVITY # = 01, REPORT CODE = 06, RECORD COUNT = 000054

0.50575E 07	0.47971E 07	0.37800E 02	0.10000E 00	23	
0.50575E 07	0.50139E 07	0.49741E 07	0.49381E 07	0.49060E 07	
0.48780E 07	0.48540E 07	0.48342E 07	0.48185E 07	0.48071E 07	R
0.48000E 07	0.47971E 07	0.47985E 07	0.48042E 07	0.48142E 07	
0.48284E 07	0.48468E 07	0.48693E 07	0.48960E 07	0.49266E 07	
0.49612E 07	0.49997E 07	0.50420E 07			

0.73517E 04	-0.75684E 04	0.37800E 02	0.10000E 00	23	
-0.75684E 04	-0.69516E 04	-0.63189E 04	-0.56714E 04	-0.50102E 04	
-0.43365E 04	-0.36519E 04	-0.29578E 04	-0.22559E 04	-0.15481E 04	
-0.83621E 03	-0.12209E 03	0.59229E 03	0.13050E 04	0.20141E 04	Ṙ
0.27177E 04	0.34140E 04	0.41013E 04	0.47781E 04	0.54427E 04	
0.60940E 04	0.67306E 04	0.73517E 04			

0.22980E 03	0.19192E 03	0.37800E 02	0.10000E 00	23	
0.22980E 03	0.22818E 03	0.22653E 03	0.22486E 03	0.22317E 03	
0.22145E 03	0.21972E 03	0.21798E 03	0.21621E 03	0.21444E 03	A
0.21267E 03	0.21089E 03	0.20911E 03	0.20733E 03	0.20555E 03	
0.20379E 03	0.20204E 03	0.20030E 03	0.19858E 03	0.19688E 03	
0.19520E 03	0.19355E 03	0.19192E 03			

-0.26744E 00	-0.29690E 00	0.37800E 02	0.10000E 00	23	
-0.26744E 00	-0.27205E 00	-0.27637E 00	-0.28036E 00	-0.28400E 00	
-0.28724E 00	-0.29005E 00	-0.29241E 00	-0.29429E 00	-0.29568E 00	
-0.29655E 00	-0.29690E 00	-0.29672E 00	-0.29603E 00	-0.29481E 00	Ȧ
-0.29309E 00	-0.29089E 00	-0.28823E 00	-0.28513E 00	-0.28162E 00	
-0.27775E 00	-0.27354E 00	-0.26903E 00			

0.80033E 00	0.64582E-01	0.37800E 02	0.10000E 00	23	
0.64582E-01	0.18495E 00	0.29590E 00	0.39693E 00	0.48757E 00	
0.56739E 00	0.63599E 00	0.69302E 00	0.73818E 00	0.77122E 00	E
0.79198E 00	0.80033E 00	0.79623E 00	0.77971E 00	0.75085E 00	
0.70982E 00	0.65684E 00	0.59219E 00	0.51621E 00	0.42928E 00	
0.33183E 00	0.22432E 00	0.10723E 00			

0.20820E-01	-0.20286E-01	0.37800E 02	0.10000E 00	23	
0.20820E-01	0.19291E-01	0.17678E-01	0.15985E-01	0.14217E-01	
0.12379E-01	0.10478E-01	0.85232E-02	0.65230E-02	0.44876E-02	
0.24278E-02	0.35469E-03	-0.17202E-02	-0.37853E-02	-0.58293E-02	Ė
-0.78413E-02	-0.98111E-02	-0.11729E-01	-0.13587E-01	-0.15377E-01	
-0.17094E-01	-0.18731E-01	-0.20286E-01			

```
03-19-76    16.108    PUNCH RADAR DATA FROM ORBIT PREDICTION PROGRAM

      CSPORB  PUNCH RADAR DATA FROM ORBIT PREDICTION PROGRAM
            DIMENSION R(1500)
            REWIND 2
            READ(02,END=100)NSEC,IDT,NN
         40 READ(02,END=100)(R(I),I=1,NN)
            RMAX = -1.0E+20
            RMIN = 1.0E+20
            DO 10 I=1,NN
            IF(R(I).GT.RMAX)RMAX=R(I)
            IF(R(I).LT.RMIN)RMIN=R(I)
         10 CONTINUE
            WRITE(6,20)RMAX,RMIN,NSEC,IDT,NN
         20 FORMAT(//2X,2E14.5,3I12/)
            PUNCH 20,RMAX,RMIN,NSEC,IDT,NN
            WRITE(6,30)(R(I),I=1,NN)
         30 FORMAT(2X,5E14.5)
            PUNCH 30,(R(I),I=1,NN)
            GO TO 40
        100 STOP
            END
```

```
0001  $     SNUMB    20844
0002  $     IDENT    CLEARY,CONTI       ,65121104RADC,DSSR
0003  $$    USERID   CLEARY$#####
0004  $     OPTION   FORTRAN
0005 A$     FORTRAN  DECK
0006  $$    PRMFL    C*,R/W,L,CLEARY/OPORB
0007  $     INCODE   IBMF
0008 A$     EXECUTE
0009  $$    PRMFL    02,R/W,L,CLEARY/STORE1
0010  $     ENDJOB
```

Sample Job Stream for Program to Punch Out Orbit Prediction Plot File

SNUMB = 20844, ACTIVITY # = 02, REPORT CODE = 06, RECORD COUNT = 000075

max.	min.	initial time	Time inc.	no. of pts.
0.22619E 04	0.92428E 03	0	5	108
0.20312E 04	0.19991E 04	0.19671E 04	0.19352E 04	0.19[illegible]35E 04
0.18719E 04	0.18405E 04	0.18093E 04	0.17783E 04	0.17474E 04
0.17168E 04	0.16863E 04	0.16561E 04	0.16261E 04	0.15964E 04
0.15670E 04	0.15378E 04	0.15090E 04	0.14804E 04	0.14523E 04
0.14244E 04	0.13970E 04	0.13700E 04	0.13434E 04	0.13172E 04
0.12916E 04	0.12665E 04	0.12419E 04	0.12179E 04	0.11946E 04
0.11719E 04	0.11499E 04	0.11286E 04	0.11082E 04	0.10885E 04
0.10698E 04	0.10519E 04	0.10351E 04	0.10192E 04	0.10[illegible]44E 04
0.99075E 03	0.97824E 03	0.96694E 03	0.95689E 03	0.94812E 03
0.94068E 03	0.93460E 03	0.92990E 03	0.92661E 03	0.92473E 03
0.92428E 03	0.92526E 03	0.92766E 03	0.93148E 03	0.93669E 03
0.94327E 03	0.95119E 03	0.96042E 03	0.97093E 03	0.98265E 03
0.99557E 03	0.10[illegible]96E 04	0.10248E 04	0.10409E 04	0.10581E 04
0.10763E 04	0.10953E 04	0.11151E 04	0.11358E 04	0.11573E 04
0.11794E 04	0.12[illegible]23E 04	0.12257E 04	0.12498E 04	0.12744E 04
0.12996E 04	0.13253E 04	0.13514E 04	0.13780E 04	0.14[illegible]51E 04
0.14325E 04	0.14602E 04	0.14884E 04	0.15168E 04	0.15456E 04
0.15746E 04	0.16[illegible]40E 04	0.16336E 04	0.16634E 04	0.16934E 04
0.17237E 04	0.17542E 04	0.17849E 04	0.18157E 04	0.18467E 04
0.18779E 04	0.19[illegible]93E 04	0.19407E 04	0.19724E 04	0.20[illegible]41E 04
0.20360E 04	0.2[illegible]680E 04	0.21[illegible]01E 04	0.21322E 04	0.21645E 04
0.21969E 04	0.22294E 04	0.22619E 04		

Range

0.35947E 03	0.19596E 00	0	5	108
0.35253E 03	0.35301E 03	0.35351E 03	0.35402E 03	0.35455E 03
0.35509E 03	0.35566E 03	0.35624E 03	0.35684E 03	0.35747E 03
0.35811E 03	0.35878E 03	0.35947E 03	0.19596E 00	0.94[illegible]89E 00
0.17153E 01	0.25196E 01	0.33554E 01	0.42239E 01	0.51271E 01
0.60668E 01	0.70446E 01	0.80628E 01	0.91233E 01	0.10228E 02
0.11379E 02	0.12578E 02	0.13829E 02	0.15132E 02	0.16491E 02
0.17906E 02	0.19382E 02	0.20918E 02	0.22518E 02	0.24182E 02
0.25913E 02	0.27710E 02	0.29575E 02	0.31507E 02	0.33505E 02
0.35569E 02	0.37697E 02	0.39884E 02	0.42129E 02	0.44425E 02
0.46769E 02	0.49152E 02	0.51569E 02	0.54012E 02	0.56472E 02
0.58940E 02	0.61409E 02	0.63868E 02	0.66311E 02	0.68727E 02
0.71110E 02	0.73453E 02	0.75748E 02	0.77992E 02	0.80178E 02
0.82304E 02	0.84367E 02	0.86364E 02	0.88294E 02	0.90157E 02
0.91953E 02	0.93681E 02	0.95344E 02	0.96941E 02	0.98476E 02
0.99949E 02	0.10136E 03	0.10272E 03	0.10402E 03	0.10527E 03
0.10646E 03	0.10761E 03	0.10871E 03	0.10977E 03	0.11[illegible]79E 03
0.11176E 03	0.11270E 03	0.11360E 03	0.11446E 03	0.11529E 03
0.11609E 03	0.11686E 03	0.11761E 03	0.11832E 03	0.11901E 03
0.11968E 03	0.12[illegible]32E 03	0.12094E 03	0.12154E 03	0.12211E 03
0.12267E 03	0.12321E 03	0.12374E 03	0.12424E 03	0.12473E 03
0.12521E 03	0.12567E 03	0.12612E 03	0.12655E 03	0.12697E 03
0.12738E 03	0.12778E 03	0.12817E 03		

Azimut

0.18796E 02	0.27345E-02	0	5	108
0.27345E-02	0.31609E 00	0.63380E 00	0.95603E 00	0.12829E 01
0.16146E 01	0.19513E 01	0.22932E 01	0.26403E 01	0.29929E 01
0.33511E 01	0.37151E 01	0.40851E 01	0.44611E 01	0.48433E 01
0.52319E 01	0.56269E 01	0.60284E 01	0.64366E 01	0.68513E 01
0.72727E 01	0.77[illegible]07E 01	0.81352E 01	0.85760E 01	0.90229E 01

Elevatio

0.94756E 01	0.99337E 01	0.10397E 02	0.10864E 02	0.11335E 02
0.11808E 02	0.12282E 02	0.12757E 02	0.13231E 02	0.13701E 02
0.14167E 02	0.14625E 02	0.15074E 02	0.15510E 02	0.15932E 02
0.16336E 02	0.16719E 02	0.17077E 02	0.17409E 02	0.17710E 02
0.17978E 02	0.18209E 02	0.18402E 02	0.18555E 02	0.18665E 02
0.18733E 02	0.18756E 02	0.18737E 02	0.18674E 02	0.18570E 02
0.18426E 02	0.18245E 02	0.18028E 02	0.17779E 02	0.17500E 02
0.17195E 02	0.16866E 02	0.16516E 02	0.16149E 02	0.15767E 02
0.15372E 02	0.14968E 02	0.14556E 02	0.14138E 02	0.13716E 02
0.13292E 02	0.12866E 02	0.12441E 02	0.12017E 02	0.11595E 02
0.11175E 02	0.10759E 02	0.10347E 02	0.99395E 01	0.95364E 01
0.91382E 01	0.87450E 01	0.83571E 01	0.79744E 01	0.75970E 01
0.72250E 01	0.68583E 01	0.64969E 01	0.61408E 01	0.57897E 01
0.54437E 01	0.51027E 01	0.47665E 01	0.44351E 01	0.41083E 01
0.37859E 01	0.34680E 01	0.31543E 01	0.28447E 01	0.25392E 01
0.22375E 01	0.19396E 01	0.16454E 01	0.13547E 01	0.10674E 01
0.78349E 00	0.50276E 00	0.22515E 00		

blank

VI. REFERENCES

R.A.Ross, RADC-TR-68-340,"Investigation of Scattering Principles-Vol. III - Analytical Investigation", May 1969 , (856560).

M.E.Bechtel & R.A. Ross, CAL Report No. ER/RIS-10, "Radar Scattering Analysis", Aug 1966.

R.A. Ross, AFAL-TR-67-343, "Investigation of Scattering Center Theory , Dec 1967.

F. Oberhettinger, "On the Diffraction & Reflection of Waves & Pulses by Wedges & Corners", Jour. Res. N.B.S, 61, 343-365(1958)

F. Oberhettinger, "Diffraction of Waves by a Wedge", Comm. Pure and Appl. Math, 7, 1954, pp 551-563.

F. Oberhettinger, "An Asympotetic Series for Functions Occurring in the Theory of Diffraction of Waves by Wedges", Jour.of Math. and Phys., 34, 1955, pp 245-255.

C.R.Stapp, "An Evaluation of the Physical Theory of Diffraction for Calculating the Radar Signature of a Finite Cone", MS Thesis For The University of Texas at Arlington, Aug 1970.

Dr. G.W.Gruver, RADC-TR-68-340, "Investigation of Scattering Principles, Vols. I, II, IV, and Addendum", May 1969.

Dr. G.W. Gruver, "An Application of Equivalence Class Techniques to Radar Signature Analysis", PHD Thesis for Oklahoma State Univ., Stillwater, OK, May 1968.

D.O. Cisco, G.P. Cable, Dr.G.W.Gruver, RADC-TR-70-257, "Radar Signature Investigation, Vols. I & II", Nov 1970, Vol I, (878303), Vol II, (878304).

R.A. Ross, "Radar Cross Section of Rectangular Flat Plates", MS Thesis for University of New York at Buffalo, NY, Feb 1966.

J. C. Cleary & P. E. Brown, 1st Lt., RADC Technical Memorandum No. EMA-TM-66-9, "Nodal Crossing Prediction Program", March 1967.

M. J. Skolnik, ed., "Radar Cross-Section of Targets", Radar Handbook, McGraw-Hill, 1969.

J. C. Cleary & L. C. Gratch, RADC Technical Memorandum RADC/OC-TM-71-4, "Cobra Talon Study Computer Programs", May 1971.

G.A. Ellis, J.F. Femia, J. Kalynycz, Jr., A.H. Proctor, RADC Technical Memorandum No. EMA-TM-66-5, "Simulation Program For Three Degrees Of Freedom Trajectories", Sept. 1966.

G.A. Ellis, RADC, RALS-TM-6103, "An Evaluation of Miss Coefficients for Impact Prediction", May 1961.

APPENDIX A

MULTIPLE TRAJECTORY PARAMETERS AND ANALYSES

The initial conditions at burnout are inputted to the computer program via NAMELIST statement. The required inputs are described in Table 5. **Table 6 describes the outputs of the computer program.** A Fortran IV listing of the computer program follows.

Resolution curves are generated for a radar site by generating a nominal trajectory and a trajectory perturbed from the nominal trajectory. The perturbation to the nominal trajectory is accomplished by using an ejection velocity at burnout. Figure 1 delineates the ejection velocity geometry at burnout.

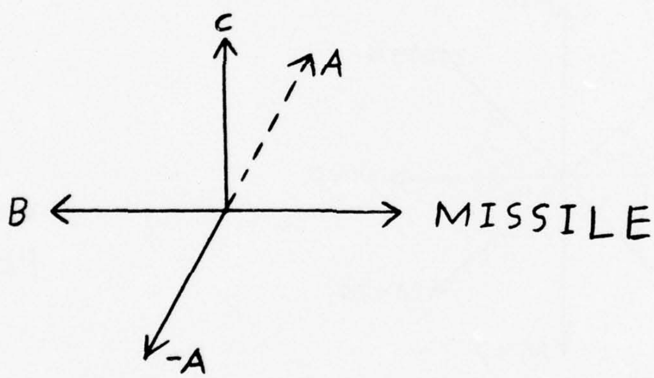


Figure 1 Ejection Velocity Geometry

BOC - plane of trajectory

BOA - plane orthogonal to trajectory plane

In the resolution analysis an inertial ejection velocity of 4.33 ft/sec at burnout was chosen. This corresponds to a non-inertial ejection velocity of 5 ft/sec (A) referenced to burnout sub-point on a rotating earth. The ejection velocity was applied in several directions as shown in Figures 2 and 3. An ejection velocity of 3.533 ft/sec

for A and B was used to maintain the ejection velocity capability (non-inertial - 5 ft/sec) at the 45 degree angle in Figure 2.

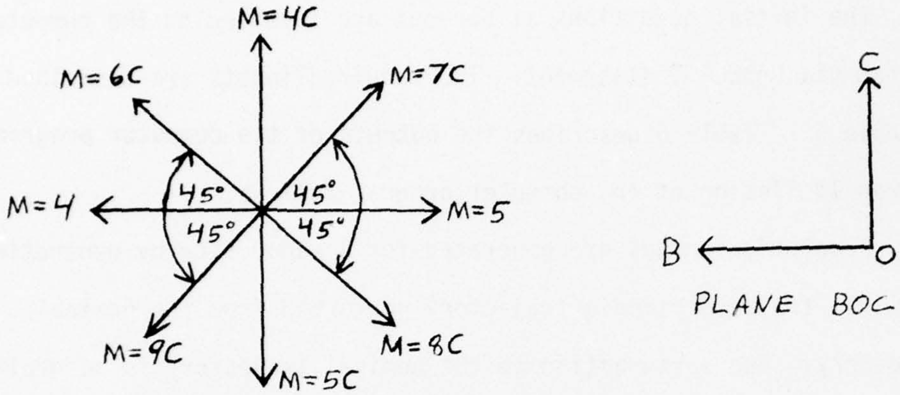


Figure 2 Ejection Velocity Geometry
Plane of the Trajectory (BOC)

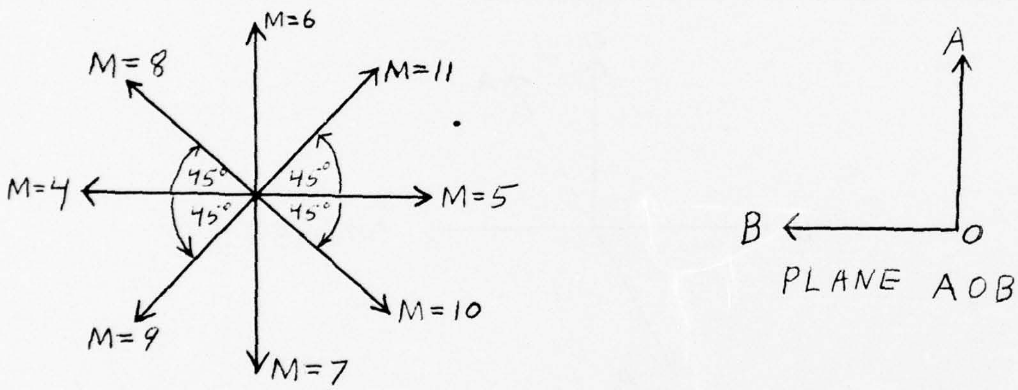


Figure 3 Ejection Velocity Geometry
Orthogonal to Trajectory Plane (AOB)

The following velocity references for the velocity perturbations at burnout were used in the computations:

Velocity Vector A (orthogonal plane AOB)	- positive when ejected to the left of the nominal trajectory
Velocity Vector B (In-plane BOC)	- positive when ejected backwards from the nominal trajectory
Velocity Vector C (In-plane BOC)	positive when ejected upwards from the nominal trajectory

The ejection velocity geometry shown in Figures 2 and 3 was selected as being representative of the maximum separations that could occur considering all possible directions of velocity perturbation.

During the course of this analysis and subsequent calculations, it was noticed that the differences observed were for all practical purposes, linear with velocity perturbation up to approximately 25 ft/sec (at ejection velocities of 100 ft/sec, the error was about 10%). Functionally, this is expressed as follows:

$$S_A = \frac{\Delta V_A}{\Delta V_B} S_B$$

where S_A = difference obtained with an ejection velocity of ΔV_A

S_B = differences obtained with an ejection velocity of ΔV_B

For example, given the resultant differences obtained with an ejection velocity of 1 ft/sec, the corresponding difference for 5 ft/sec would be 5 times as large.

It was also found that a velocity ejection equal but opposite in direction produced similar results, i.e., the corresponding observed trajectory differences were equal but opposite in sign, (again valid up to an ejection velocity of approximately 25 ft/sec). This is summarized in the following table:

IN PLANE (BOC)	ORTHOGONAL PLANE (AOB)
$SM_4 = -SM_5$	$SM_4 = -SM_5$
$SM_{4c} = -SM_{5c}$	$SM_6 = -SM_7$
$SM_{7c} = -SM_{9c}$	$SM_8 = -SM_{10}$
$SM_{6c} = -SM_{8c}$	$SM_{11} = -SM_9$

Table 4 Negative Relationships of Ejection Velocities

Where "SM_4" denotes the separations observed in the M_4 direction, "SM_5" that in the M_5 direction and so on.

Because of these relationships and since the M_4 and M_5 directions are common to both planes only 7 curves, instead of 16 are required to specify the observed differences for a velocity of a given magnitude. It follows that the number of computations required to determine these differences for the selected directions of ejection are correspondingly reduced. Observed differences in range, range rate and angle vs time after burnout were plotted.

For example: the following set of perturbation velocities would give the resolution requirements for all the cases specified in Figures 2 and 3 for a non-inertial ejection velocity capability of 5 ft/sec.

M	A	B	C
4c	0	0	5
4	0	5	0
6c	0	3.533	3.533
7c	0	-3.533	3.533
6	5	0	0
8	3.533	3.533	0
11	3.533	-3.533	0

For the 45° angle case use .7067 ft/sec for a 1 ft/sec non-inertial capability, 7.067 ft/sec for the 10 ft/sec case, 17.67 ft/sec for the 25 ft/sec case, and 70.7125 ft/sec for the 100 ft/sec case.

Note that the resultant inertial velocity for a fixed non-inertial velocity is a function of launch azimuth (direction), launch angle (reentry angle) and launch altitude (burnout). Once the non-inertial velocity was selected, the launch angle and launch altitude were not varied and consequently, the final inertial velocity was a function of launch azimuth only. This relationship is shown in Figure 15. The inertial ejection velocity for a given non-inertial ejection velocity is also a function of launch azimuth and varies in the same manner. For instance, if the launch azimuth were about 180° instead of 225°, the inertial velocity and non-inertial velocity would be about equal, and if the launch azimuth were about 90°, the resultant inertial velocity would be larger than the non-inertial velocity and approach its maximum value.

An analysis was also done to determine the Ejection Velocity Separation Errors. For all practical purposes, observed trajectory differences are directly proportional to the velocity perturbation and that velocity perturbations equal in magnitude, but opposite in direction, produced the same observed separations in correspondingly opposite directions. These are referred to as the "linear" and "negative" relationships respectively, and were considered valid for velocity perturbations up to approximately 25 ft/sec. They are expressed as follows:

Linear Relationships

$$S_A = \frac{\Delta V_A}{\Delta V_B} S_B$$

where S_A = difference obtained with an ejection velocity of ΔV_A

S_B = difference obtained with an ejection velocity of ΔV_B

Negative Relationships (refer to Figure 8)

IN PLANE			ORTHOGONAL PLANE		
S_{M4}	=	$-S_{M5}$	S_{M4}	=	$-S_{M5}$
S_{M4C}	=	$-S_{M5C}$	S_{M6}	=	$-S_{M7}$
S_{M7C}	=	$-S_{M9C}$	S_{M8}	=	S_{M10}
S_{M6C}	=	$-S_{M8C}$	S_{M11}	=	$-S_{M9}$

Where S_{M4} denotes the separations observed in the M_4 direction, S_{M5} in the M5 direction, and so on.

In this section, the errors involved in assuming these functional relationships are delineated, and are based on comparison of actual trajectory information.

The data used for this purpose was generated for a variety of velocity perturbations (ejections) which took place at burnout (approximately 400,000 ft. alt.) on a nominal 5500 NM missile trajectory.

Trajectory differences in range, range rate, and angle vs time as observed at the radar, were plotted for incremental (non-inertial) velocity ejections of 1, 5, 10, 25, and 100 ft/sec. Both in-plane and orthogonal-plane perturbations were considered in the directions as indicated in Figure 8. Initial analysis of this data revealed that in making these assumptions ("linear" and "negative" relationships), that in general, bodies ejected in the M = 5 direction (Refer to Figure 8) produced the largest observable separations. The preceding combination represents worst case errors for the application considered, and the errors discussed in this section are derived from this example. Resulting errors associated with making the aforementioned assumptions would be smaller for different conditions, i.e. observation from a different radar and/or different direction of velocity ejection.

Since assumptions of the "linear" and "negative" relationships are shown valid for a rather specific application, caution must be exercised when extending these assumptions to other conditions of launch and observation. The proof here is emperical rather than analytical, and must be considered as such. In the example specified (observation from a specific radar, ejection in the M = 5 direction), the errors in assuming that the observed trajectory differences are "linear" with ejection velocity are plotted in Figures 4 thru 7; those associated

with the "negative" relationships are plotted in Figures 11 thru 12.

In Table 7, the actual computed separations in range (NM) as observed at the radar for velocity perturbations of 1, 5, 10, 25 feet per second (FPS) are tabulated for three minute intervals, (actual perturbations took place at $t = 0$, but were *not* observed until some 9 minutes later because of line-of-site limitations).

t (min)	1 FPS	5 FPS	10 FPS	25 FPS
9	-.00431	-.02151	- .04295	- .10683
12	.02301	.11514	.23043	.57729
15	.07102	.35522	.71069	1.77870
18	.13273	.66375	1.32781	3.32183
21	.16711	.88579	1.67214	4.18445
24	.13645	.68282	1.36701	3.42774

Table 7 Range Separations (NM)

(M = 5 direction)

The 1 FPS values were then multiplied by 5, 10, 25 and the 5 FPS value by 5 respectively. Listed in Table 8 are the differences between these values (1 FPS X 5, 1 FPS x 10, 1 FPS X 25, and 5 FPS X 5) and the corresponding values in Table 7 (5 FPS, 10 FPS, 25 FPS, and 25 FPS). The results represent the maximum differences (error in NM) between the actual values and those which would be obtained by assuming the linear relationship.

t(min)	1FPSx5 - 5FPS	1FPSx10 - 10FPS	1FPSx25 - 25FPS	5FPSx5 - 25FPS
9	.00003	.00013	.00089	.00074
12	.00006	.00029	.00193	.00161
15	.00011	.00048	.00317	.00263
18	.00013	.00055	.00369	.00307
21	.00022	.00101	.00663	.00551
24	.00055	.00246	.01637	.01364

Table 8 Linear Range Separation Errors (NM) M = 5)

As indicated in Table 8 the maximum error occurs when the 1 FPS separation is multiplied by 25 and then subtracted from the actual 25 FPS separation (t = 24 min). In Table 7, at t-24, the value of 1 FPS is equal to .13645 NM, this value when multiplied by 25 and subtracted from the corresponding value at 25 FPS (3.42274) is equal to .01637 NM, which is about 100 ft. The actual separation at this time is roughly 20,000 ft. Thus, the 100 ft. represents a worst case error of approximately 0.5% and is within tolerable limits.

It is pointed out that the observed separations as a function of velocity perturbations were determined to ascertain the range resolution requirements of the radar system. The interest in resolving targets is for the purpose of obtaining good metric data, and therefore targets must be resolved as soon as possible after initial detection. For the particular case chosen here, the time of initial detection is about 9 minutes after burnout, and the target swarm would be within the radar field-of-view for some 16 minutes thereafter.

Assuming that detected targets are to be resolved within 3 minutes after initial detection (12 minutes after launch), the maximum error (Table 8) is .00193 NM (roughly 12 ft) and is 0.33% of the total range separation which is .57729 NM (3600 ft) at this time.

The same procedure was used in establishing the angle errors. For this case maximum angle errors also occurred about 24 minutes after launch, and were about 0.3% for elevation and 0.2% azimuth. Actual elevation and azimuth errors for the linear relationship are plotted in Figures 5 and 6. In these figures, the 1/5, 1/10, etc. represent the 1 FPS multiplied by 5, the 1 FPS by 10, and so on.

Range rate errors associated with the linear relationship were determined by the same method and are shown in Figure 7. The largest error calculated in this manner was less than 0.4 ft/sec which corresponds to the difference between the 25 FPS value and the 1 FPS value multiplied by 25; both taken at t = 24 minutes. At this time, the observed range rate separation between the nominal trajectory and the one perturbed by 25 FPS was approximately 50 ft/sec. It is thus seen that the 0.4 ft/sec error is rather insignificant. The preceding errors are summarized in the table below:

Observables	Nom. Traj.	Difference (Non-perturbed)	Error (Linear)	% Error
Range	1200 NM	20,000 ft	100 ft.	0.5%
Range Rate	9000 ft/sec	50 ft/sec	0.4 ft/sec	0.8%
Elevation	19 deg.	0.3 deg	0.001 deg	0.3%
Azimuth	225 deg(true)	0.06 deg.	0.0001 deg	0.2%

Table 9 Error Summary Linear Relationship
LR, M=5, 1FPSx25 - 25 FPS , t=24)

The errors resulting from assuming the validity of the negative relationship was found by taking the difference between equal but oppositely directed velocity perturbation, i.e. $S_{M4} - S_{M5}$, $S_{M6} - S_{M7}$, etc. (Refer to Figure 8). The errors (in range, range rate and angle) were determined for a velocity perturbation of 25 ft/sec (worst case). If the resulting error here can be tolerated, then the error for smaller velocity perturbations would also be acceptable. Illustrated in Table 10 are the range errors associated with assuming the negative relationship for a velocity perturbation of 25 ft/sec at two minute intervals.

Time(Min)	$S_{M4} - S_{M5}$	$S_{M6} - S_{M7}$	$S_{M8} - S_{M10}$	$S_{M9} - S_{M11}$
10	15	13	18	10
12	24	21	31	14
14	35	32	49	17
16	43	45	74	15
18	47	61	101	7
20	63	75	132	5
22	120	82	170	32
24	208	81	215	74

Table 10

Negative Range Errors (feet) LR,ΔV = 25 ft/sec)

It is thus seen that the maximum error in range under these conditions is 215 ft. The actual range difference between the nominal trajectory and the one perturbed by 25 ft/sec for this example is approximately 10,000 ft. and consequently, an error of 25 ft/sec is

considered insignificant. In this case range rate error is about 1 ft/sec out of a 30 ft/sec difference; and azimuth and elevation errors are practically lost in the noise. All these errors are summarized in the table below:

Observable	Nominal Traj.	Difference Nom - Pert.	Error Neg.	Error %
Range	1200 NM	10,000 ft.	215 ft.	2.2%
Range Rate	9000 ft/sec	30 ft/sec	1 ft/sec	3.3%
Elevation	19 deg.	0.3 deg	0.002 deg	0.7%
Azimuth	255 deg (true)	0.13 deg	0.0005 deg	0.4%

Table 11

Error Summary - Negative Relationship

LR, ΔV = 25 ft/sec, t = 24, S_{M8} - S_{M10}

It is evident from Tables 9 and 11 that the errors associated with the assumptions of both the linear and negative relationships are within reasonable limits for the selected (worst case) example.

It is thus concluded that

1. the differences in range, range rate, and angle, as observed by this radar are for most practical purposes, linear with respect to ejection velocities up to 25 ft/sec.

2. the observed differences for range, range rate and angle can be assumed equal in magnitude for equal but opposite velocity separations also up to approximately 25 ft/sec (the geometry of ejection is illustrated in Figure 8).

At velocity perturbations up to 100 ft/sec, most of the errors discussed in the example here, were in the order of 10% of the actual observed difference between the nominal trajectory and the one perturbed by 100 ft/sec. It was thus concluded that the linear and negative relationships were not valid for an ejection velocity of 100 ft/sec, but that they can be used with very good accuracy for velocity perturbations up to approximately 25 ft/sec.

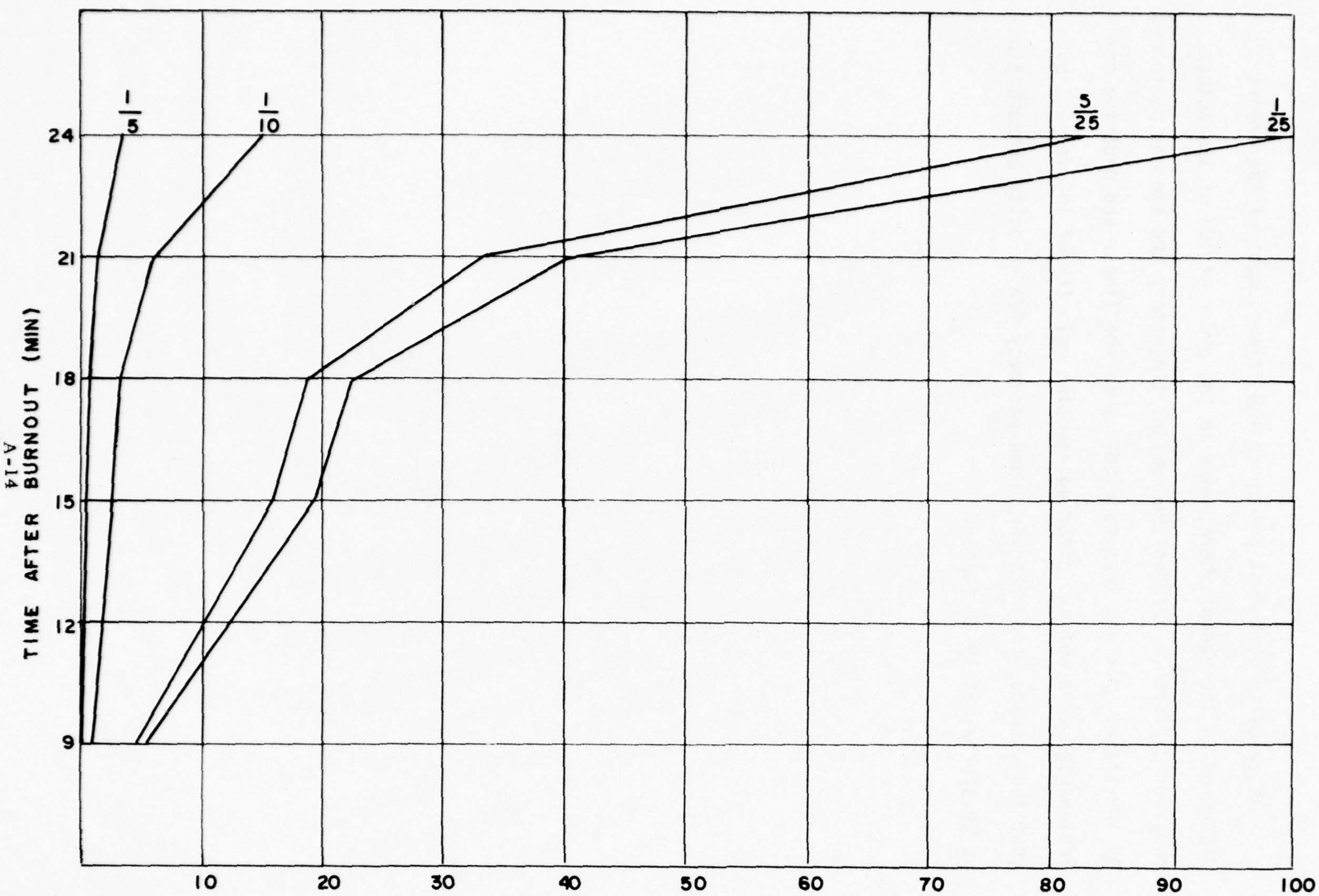


Figure 4. LINEAR ERROR-RANGE DIFFERENCE (FEET) (DG-225 LR, M=5)

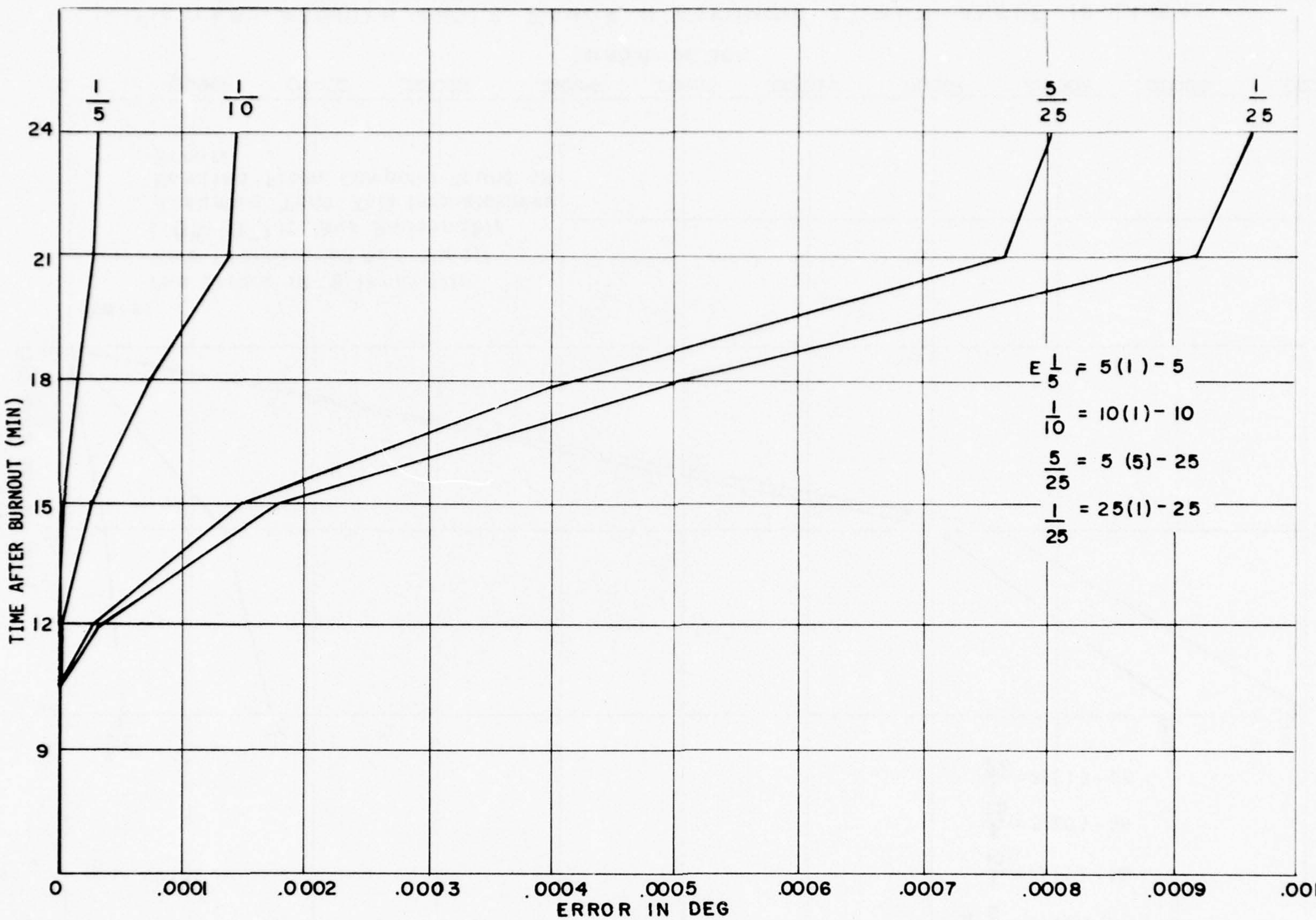


Figure 5. ELEVATION AND ERROR IN ASSUMING ANGLE SEPERATION IS LINEAR WITH EJECTION VELOCITY (DG - 225)

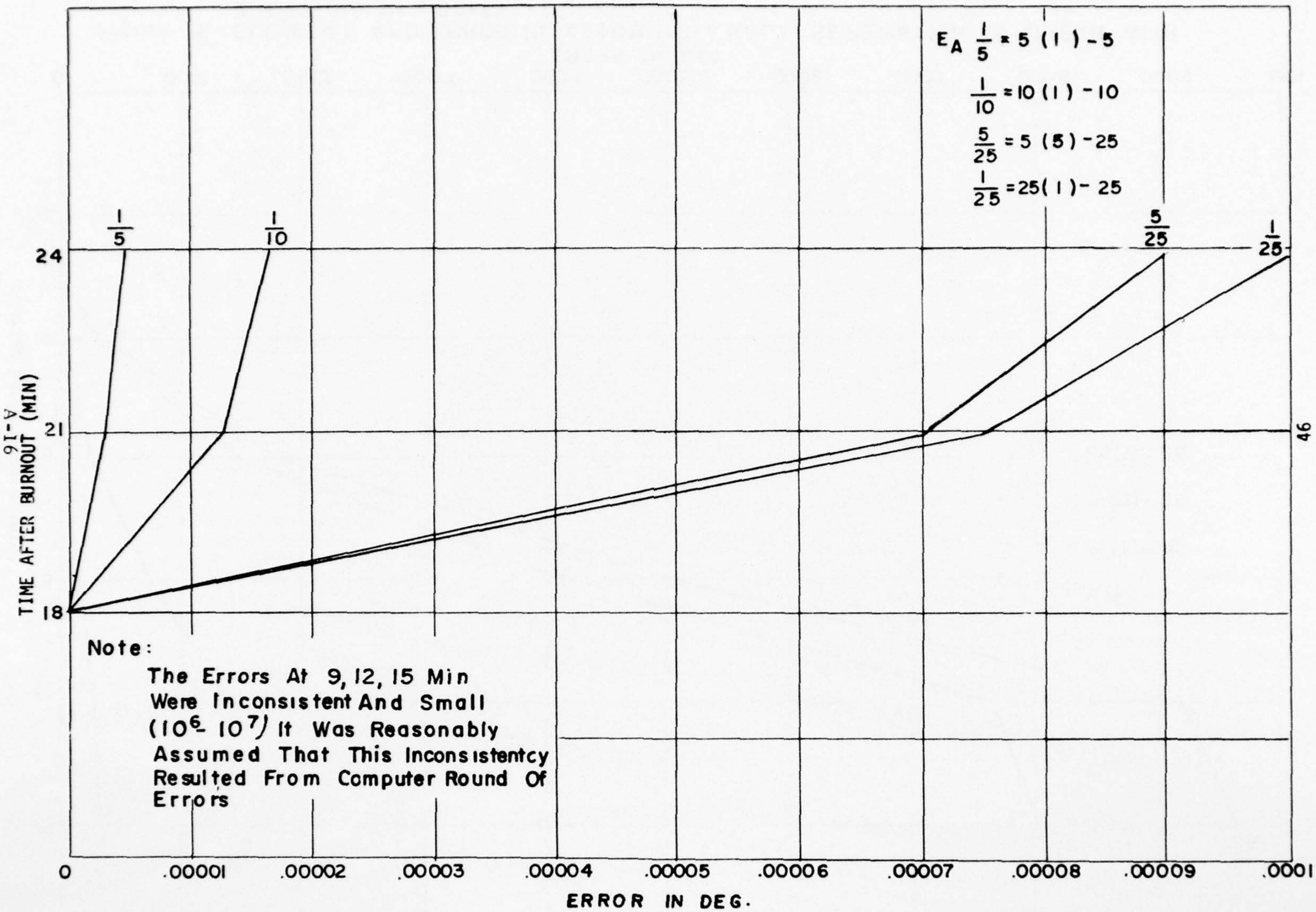


Figure 6. AZIMUTH ANGLE ERROR IN ASSUMING AZIMUTH ANGLE IS LINEAR WITH EJECTION VELOCITY (DG-225)

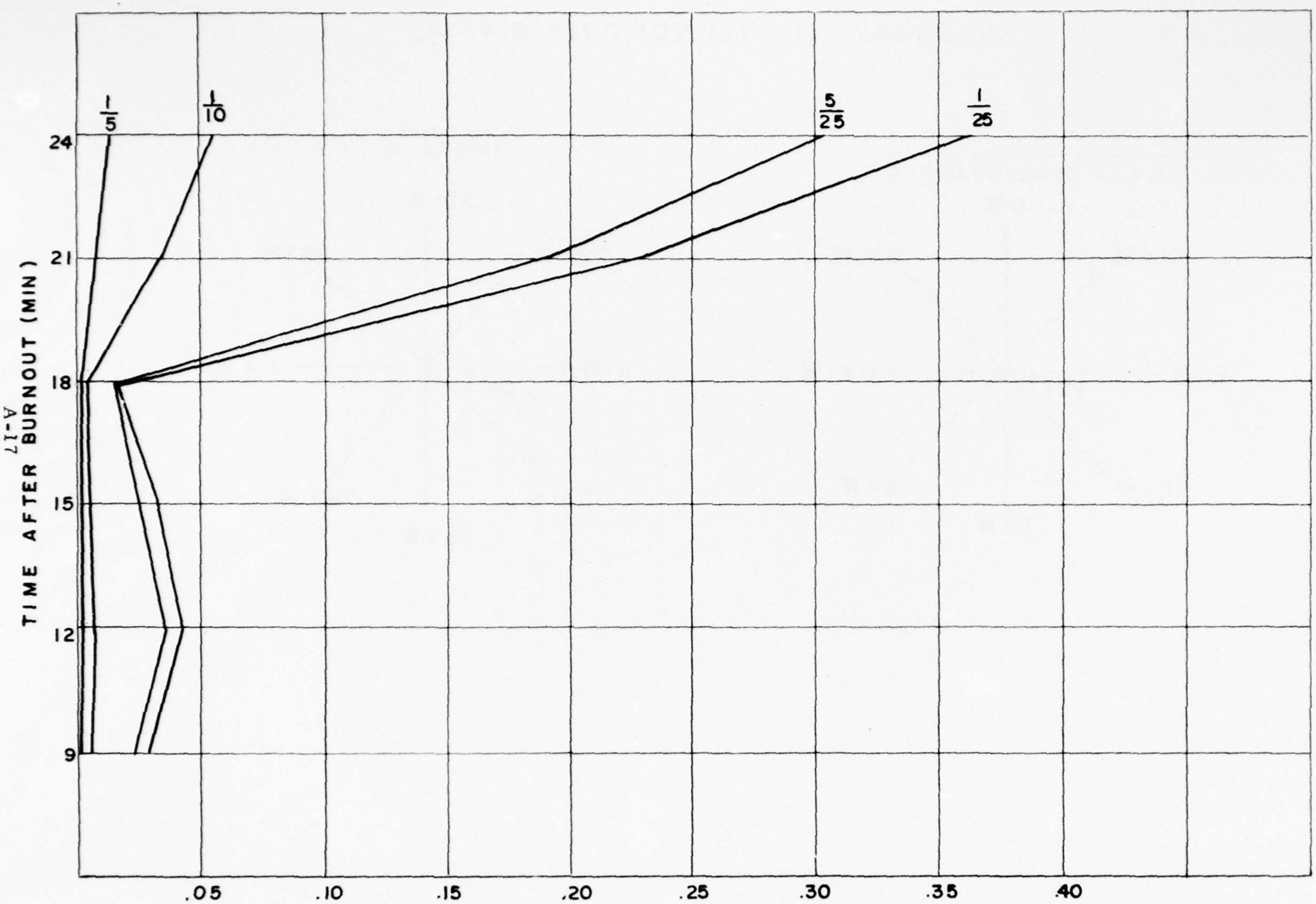
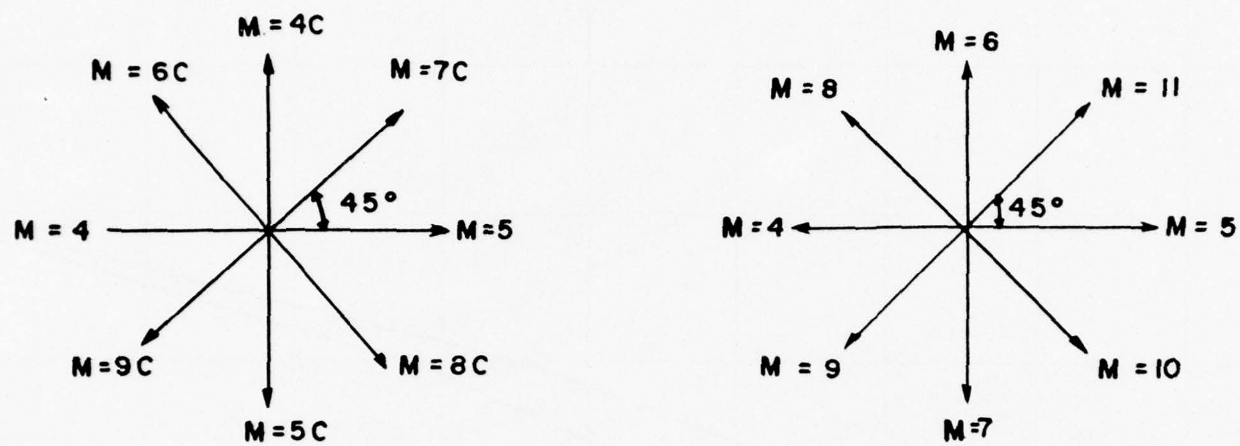


Figure 7. LINEAR ERROR RANGE RATE DIFFERENCE (Ft/Sec) (DG-225 LRM=5)



a - IN PLANE

b -ORTHOZONAL PLANE

Figure 8. EJECTION VELOCITY GEOMETRY

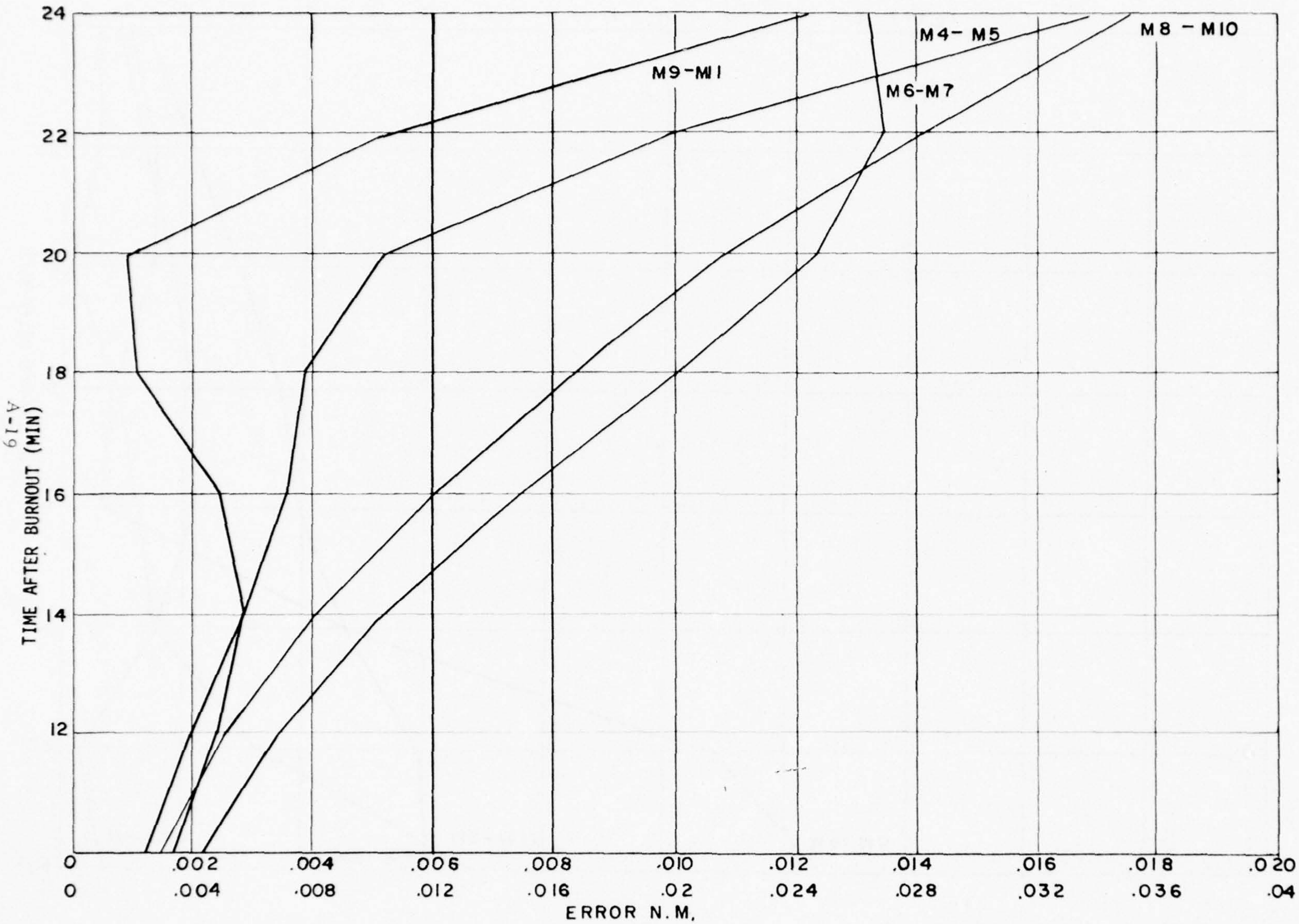


Figure 9. RANGE ERROR IN ASSUMING NEGATIVE RELATIONSHIPS OF EJECTION VELOCITIES IN TABLE 4 (DG-225)

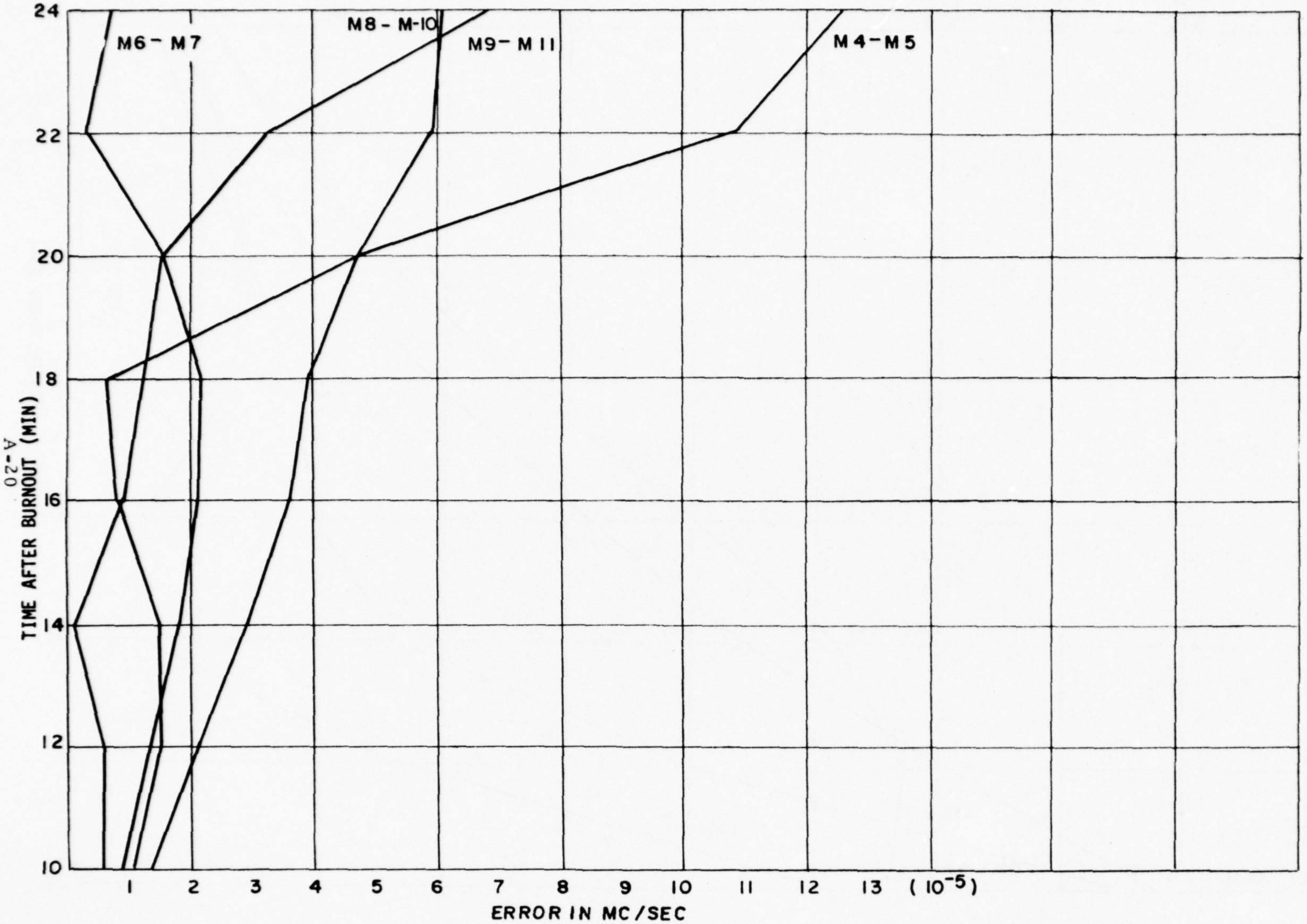


Figure 10, RANGE RATE ERROR RATE IN ASSUMING NEGATIVE RELATIONSHIPS OF EJECTION VELOCITIES IN TABLE 4 (DG-225)

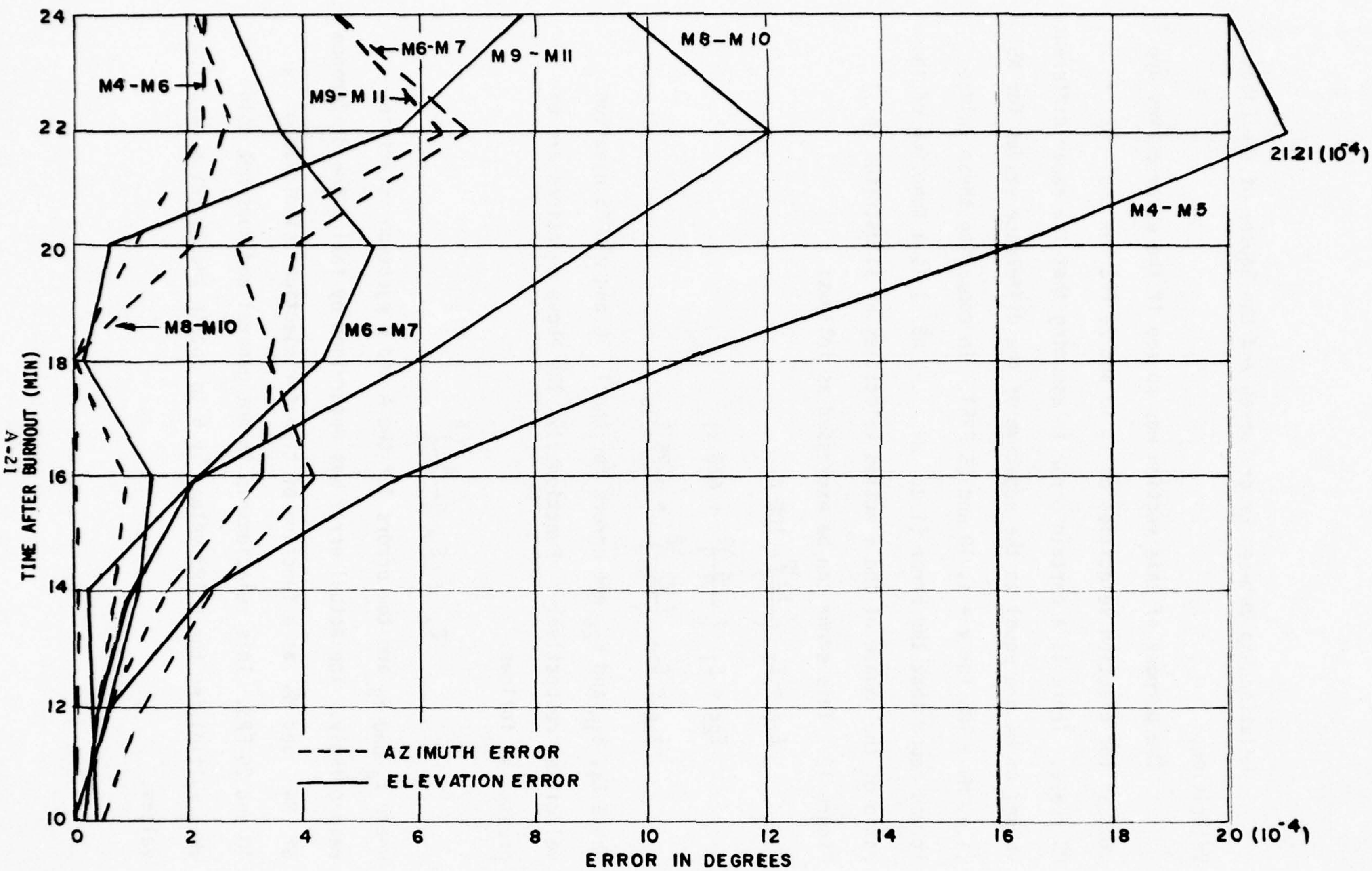


Figure 11. ANGLE ERROR IN ASSUMING NEGATIVE RELATIONSHIPS OF EJECTION VELOCITIES IN TABLE 4 (DG-225)

Relationship Between Error Curves and the Square of the Ejection Velocities.

The purpose of this section was to see if the error curves are similar for ejection velocities of 1, 10 and 25 FPS for the M4 = M5 case. There is a certain error in assuming that the radar difference values of M4 are equal to the negative of the difference values for M5 (i.e. M4 - -M5 for v = 1, 10 and 25 FPS). In comparing these values it was found that the error (i.e. M4 - M5) is a function of the ratio of the square of the ejection velocities as illustrated in Figure 12. This error can be expressed as follows:

$$E_{10} = E_1 \left(\frac{10}{1}\right)^2 = 100\ E_1$$

$$E_{25} = E_1 \left(\frac{25}{1}\right)^2 = 625\ E_1$$

$$E_{25} = E_{10} \left(\frac{25}{10}\right)^2 = 6.25\ E_{10}$$

where E_1, E_{10} and E_{25} are errors for the 1, 10 and 25 FPS ejection velocities respectively. Functionally, the above equations are expressed as follows:

$$E_A = E_B \left(\frac{A}{B}\right)^2$$

where E_A and E_B are the errors for the A and B ejection velocities respectively. The actual error was determined by taking the difference of M4 and M5 as a function of time for ejection velocities of 1, 10 and 25 FPS. This relationship is not general and does not hold when multiplying the 5 FPS values by 5 to obtain the 25 FPS separation values.

Conclusions

The preceding pages illustrate that the differences in range, range rate, elevation and azimuth as seen by a radar are linear with respect to ejection velocity up to approximately 25 FPS. These differences can be expressed as follows:

a. If one wishes to determine the differences at an ejection velocity of 5 FPS, one simply multiplies the value of the radar difference obtained at 1 FPS by 5. Similarly, for the values at 10 FPS, multiply by 10 and for the values at 25 FPS, multiply by 25. This applies to range, range rate, azimuth and elevation. It is noted that the percentage of error is largest when one obtains the radar separations for an ejection velocity of 25 FPS by multiplying the 1 FPS radar difference values by 25, but even in this case the errors are within reasonable limits.

b. It was also concluded that the radar differences for range, range rate, azimuth and elevation are equal in magnitude for equal but opposite velocity separations as illustrated in Figure 9 through 11. That is, if a body was ejected in the M4 direction with a velocity V, not to exceed 25 FPS, then the separations as seen by the radar would have approximately the same magnitude as that seen for a body ejected in the M5 direction with an ejection velocity V. It is noted that the actual values are the negative of each other. For example, if at some time T (arbitrarily selected) after ejection, one difference as seen by the radar (range, range rate, azimuth or elevation) is equal to a value A for the M4 direction, it would be approximately

equal to minus A for the M5 direction.

This is expressed as follows:

$$M4 = -M5$$

$$M6 = -M7$$

$$M8 = -M10$$

$$M9 = -M11$$

This applies to all other directions that are equal and opposite to each other.

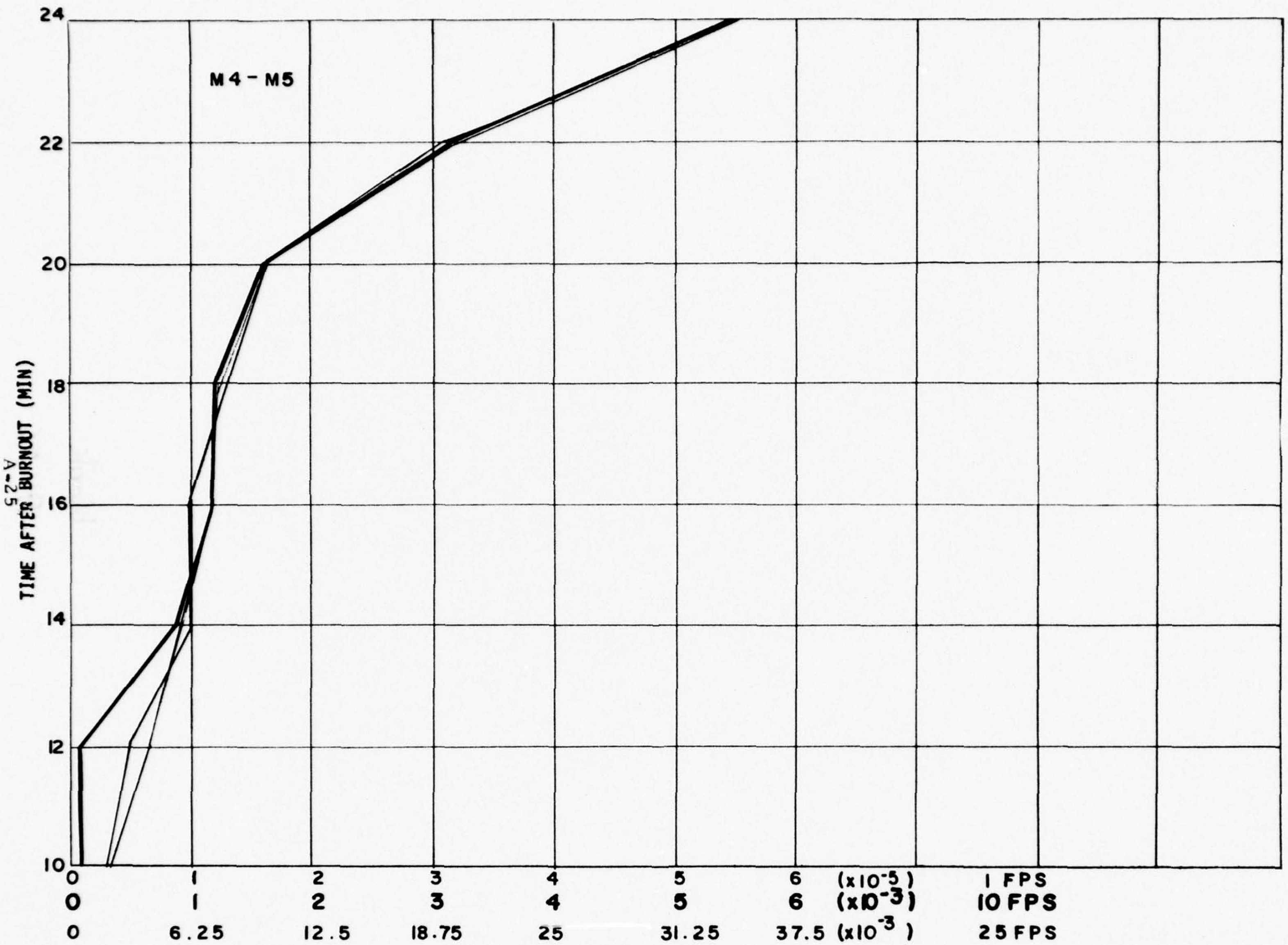


Figure 12. RELATIONSHIP BETWEEN ERROR CURVES AND THE SQUARE OF THE EJECTION VELOCITIES (DG-225)

APPENDIX B

MISSILE SURFACE RANGE COMPUTER PROGRAM

Given missile launch and impact points on a spherical earth (i.e., co-latitudes and longitude differences in degrees), computer program SURFACE determines the missile heading angles and missile surface range in degrees and nautical miles.

Figure 13 shows the geometry of the situation. The following terminology is used in conjunction with Figure 13:

A = co-latitude of launch

B = co-latitude of impact

D = longitude difference between the impact and launch points

S = missile surface range

β = missile heading angle measured clockwise from true north for the case when β is greater than 180 degrees

C = missile heading angle measured clockwise from true north for the case when β is less than 180 degrees

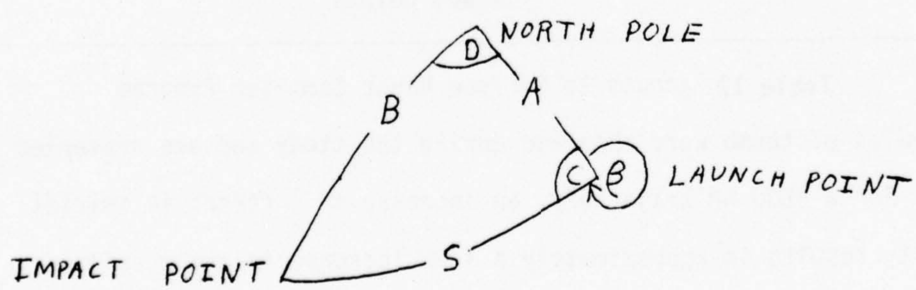


Figure 13 Missile Surface Range Geometry

Applying spherical trigonometry to the triangle in Figure 13 yields the following equations:

$$S = \arccos(\cos B \cos A + \sin B \sin A \cos D) \quad (1)$$

$$C = \arcsin(\sin B \sin D / \sin S) \quad (2)$$

$$\beta = 360° - C \quad (3)$$

These equations have been programmed for the RADC GE645 time sharing system. The required inputs to the program are shown below.

INPUTS

PROGRAM SYMBOL	UNITS	MATH SYMBOL	MEANING
N			Number of cases to be run, must be greater than 1 - the first case could be a test case to insure that the computer is functioning correctly.
AL(J)	degrees	A	co-latitude of launch point
BI(J)	degrees	B	co-latitude of impact point
DL(J)	degrees	D	longitude difference between launch and impact points

Table 12 Inputs to Surface Range Computer Program

Some rules of thumb were observed during the study and are presented here. For a 5500 NM trajectory, an increase of 1 ft/sec in initial velocity results in approximately a 1 NM increase in the missile's surface range. To keep the surface range roughly constant (5500 NM case) when increasing the launch altitude by 1000 ft, decrease the initial velocity by 1 ft/sec.

```
*     PROGRAM CALCULATES SURFACE RANGE AND MISSILE HEADING
*     ANGLE  *** GIVEN LAUNCH AND IMPACT COORDINATES IN DEG.
*           FOR NONROTATING EARTH
*              INPUTS
*     N = NUMBER CASES, MUST BE > 1
*        CASE 1 IS TEST CASE *** ANSWERS  SURFACE RANGE IS
*         52.6333333 DEG. AND  BETA = 277.2 DEG.
*      AL(J) = COLATITUDE OF LAUNCH POINT          IN DEG.
*     ALL(J) = LONGITUDE OF LAUNCH POINT           IN DEG.
*     BI(J) = COLATITUDE OF IMPACT POINT          IN DEG
*     BII(J) = LONGITUDE OF IMPACT POINT           IN DEG.
*     DL(J) = LONGITUDE DIFFERENCE                 IN DEG.
      DIMENSION AL(10),BI(10),ALL(10),BII(10),DL(10)
      DIMENSION AL1(10),BI1(10),DL1(10),COSS(10),S(10)
      DIMENSION SM(10),SINC(10),C(10),BETA(10)
      DIMENSION SD(10)
      DIMENSION CD(10)
      DTR = 1.74532925E-2
      RTD = 57.2957795
      PI = 3.14159265
  DATA N/5/
      DATA AL(1),ALL(1)/128.7,250.3/
      DATA BI(1),BII(1)/107.55,306.1/
      DATA DL(1)/55.8/
*         9 CASES + CHECK CASE
      NN = N-1
  DATA AL(2),BI(2),DL(2)/42.5,34.25,160.583333/
  DATA AL(3),BI(3),DL(3)/42.5,30.0833333,153.183333/
  DATA AL(4),BI(4),DL(4)/42.0666667,34.25,145.583333/
  DATA AL(5),BI(5),DL(5)/42.0666667,30.083333,138.083333/
      PRINT 40,(AL(M),BI(M),DL(M),M=1,10)
444   CONTINUE
      DO 5555 J=1,N
      AL1(J) = AL(J)*DTR
      BI1(J) = BI(J)*DTR
      DL1(J) = DL(J)*DTR
      COSS(J) = COS(BI1(J))*COS(AL1(J))+SIN(BI1(J))*SIN(AL1(J))*
&     COS(DL1(J))
      S(J) = ARCOS(COSS(J))
      SD(J) = S(J)*RTD
      SM(J) = SD(J)*60.0
      SINC(J) = SIN(BI1(J))*SIN(DL1(J))/SIN(S(J))
      C(J) = ARSIN(SINC(J))
      CD(J) = C(J)*RTD
      PRINT 60,SD(J)
      PRINT 70,SM(J)
      PRINT 75,CD(J)
      BETA(J) = (2.0*PI-C(J))*RTD
      PRINT 80,BETA(J)
      PRINT 90,J
  40  FORMAT(1H0,3(F10.5))
60    FORMAT(1H0,"SURFACE RANGE = ",F12.6,"DEG")
70    FORMAT(1H0,"SURFACE RANGE = ",F12.6,"N.M.")
75    FORMAT(1H0,"CD(J) = ",F12.6)
80    FORMAT(1H0,"MISSILE HEADING ANGLE = ",F12.6,"DEG")
90    FORMAT(1H-,10X,"END OF CASE",I4)
100   FORMAT(1H-)
5555  CONTINUE
      STOP
      END
```

128.70000	107.55000	55.80000
42.50000	34.25000	160.58333
42.50000	30.08333	153.18333
42.06667	34.25000	145.58333
42.06667	30.08333	138.08333
0.	0.	0.
0.	0.	0.
0.	0.	0.
0.	0.	0.
0.	0.	0.

SURFACE RANGE = 52.642729DEG

SURFACE RANGE = 3158.563751N.M.

CD(J) = 82.790698

MISSILE HEADING ANGLE = 277.209293DEG

END OF CASE 1

SURFACE RANGE = 75.473641DEG

SURFACE RANGE = 4528.418457N.M.

CD(J) = 11.143965

MISSILE HEADING ANGLE = 348.856026DEG

END OF CASE 2

SURFACE RANGE = 70.382569DEG

SURFACE RANGE = 4222.954102N.M.

CD(J) = 13.890757

MISSILE HEADING ANGLE = 346.109234DEG

END OF CASE 3

SURFACE RANGE = 72.388386DEG

SURFACE RANGE = 4343.303101N.M.

CD(J) = 19.496184

MISSILE HEADING ANGLE = 340.503811DEG

END OF CASE 4

SURFACE RANGE =   66.892219DEG

SURFACE RANGE = 4013.533112N.M.

CD(J) =   21.350734

MISSILE HEADING ANGLE =   338.649258DEG

END OF CASE   5

APPENDIX C

Initial Missile Velocity Computer Program and Effects of Earth's Rotation on a Missile's Initial Inertial Velocity and Surface Range

A. Program Rotate

The following equation determines a missile's inertial velocity:

$$VI = VO\sqrt{\cos^2\gamma + \left[\cos^2\beta + \left(1 + \frac{\omega}{VO_R \sin\gamma \sin\beta / R\cos\theta + \omega}\right)\sin^2\beta\right]\sin^2\gamma} \tag{4}$$

VI = missile's initial inertial velocity at burnout

VO = Missile's initial velocity relative to burnout, rotation of earth is not considered when VO is determined*

β = missile heading angle measured clockwise from north

γ = missile's reentry angle measured from the vertical

RE = earth's radius

HX = missile's altitude at burnout

R = RE + HX, geocentric radius to the missile at burnout

ω = earth's rotation rate

θ = launch latitude of the missile

With a missile heading angle of 180°, a 6020 NM missile surface range capability was assumed. A shorter surface range missile capability of 3890 NM was also investigated. Figure 14 shows dependence of the missile's surface range on the missile heading angle β . It is readily seen that a change of 130° in β corresponds to a change in the missile surface range of 1370 NM for the long range case and 540 NM for the short range case. In Figure 15 the dependence of the missile's initial inertial velocity (VI) on the missile heading angle β is shown. For the long range case a change in β of 130° corresponds to a change of 1900 ft/sec and a change of 2000 ft/sec

*See Section VB "Initial Missile Velocity Program"

in the short range case. Thus the rotation of the earth has a definite effect on the initial conditions required to impact in a specific target area.

One way to zero in on the impact area is to rotate the earth backwards and pick a new VO as the initial velocity input to the missile trajectory program. To that end the rotation of the earth (ω) in equation 4 was replaced by $-\omega$ and programmed for the RADC GE 645 time-sharing system. This proved to be very useful in zeroing in on the impact point for the case where atmospheric drag is not considered or for short range (1000 NM surface range or less) trajectories when the atmosphere is used. For longer range surface ranges, when atmospheric drag is considered, it is better to use the original value of VO calculated with the "Initial Missile Velocity Program".

The following table delineates the inputs required by computer program rotate.

INPUTS

Program Symbol	Units	Math Symbol	Meaning
G	DEG	γ	Missile reentry angle measured from vertical
B	DEG	β	Missile heading angle measured clockwise from North
T	DEG	θ	Launch latitude of the missile
VO	FT/MIN	VO	Missile's initial velocity relative to burnout
HX	VT	$H\chi$	Missile's altitude at burnout

Table 13 Inputs to Program Rotate

Some rules of thumb were observed during the study and are presented here. For a 5500 NM trajectory, an increase of 1 ft/sec in initial velocity results in approximately a 1 NM increase in the missile's surface range. To keep the surface range roughly constant (5500 NM case) when increasing the launch altitude by 1000 ft., decrease the initial velocity by 1 ft/sec.

MINIMUM ENERGY		HX = 400,000 ft.		
Surface Range NM	CA (Deg)	GAM (Deg)	VØ (Ft/Min)	VØ (Ft/Sec)
100	1.66482	61.95	191,774	3,196.23
200	3.32964	54.85	311,846	5,197.44
300	4.99446	52.4	399,722	6,662.04
400	6.65928	51.3	470,770	7,846.16
500	8.32410	50.8	531,212	8,853.53
600	9.98892	50.6	584,202	9,736.69
700	11.6537	50.55	631,582	10,526.4
800	13.3186	50.6	674,538	11,242.3
900	14.9834	50.8	713,886	11,898.1
1000	16.6482	51.0	750,216	12,503.6
1500	24.9723	52.5	899,163	14,986.1
2000	33.2964	54.2	1,011,828	16,863.8
2500	41.6205	56.1	1,101,326	18,355.4
3000	49.9446	58.1	1,174,466	19,574.4
3500	58.2687	60.1	1,235,337	20,588.9
4000	66.5928	62.1	1,286,623	21,443.7
4500	74.9169	64.1	1,330,193	22,169.9
5000	83.2410	66.1	1,367,403	22,790.1
5500	91.5651	68.15	1,399,266	23,321.1
6000	99.8892	70.2	1,426,555	23,775.9
6500	108.213	72.25	1,449,876	24,164.6
7000	116.537	74.3	1,469,698	24,495.0
7500	124.862	76.35	1,486,400	24,773.3
8000	133.186	78.4	1,500,274	25,004.6
8500	141.510	80.5	1,511,558	25,192.6
9000	149.834	82.5	1,520,432	25,340.5
9500	158.158	84.6	1,527,034	25,450.6
10000	166.482	86.65	1,531,466	25,524.4

Table 14 Surface Range vs Reentry Angle & Initial Non-inertial Velocity Data

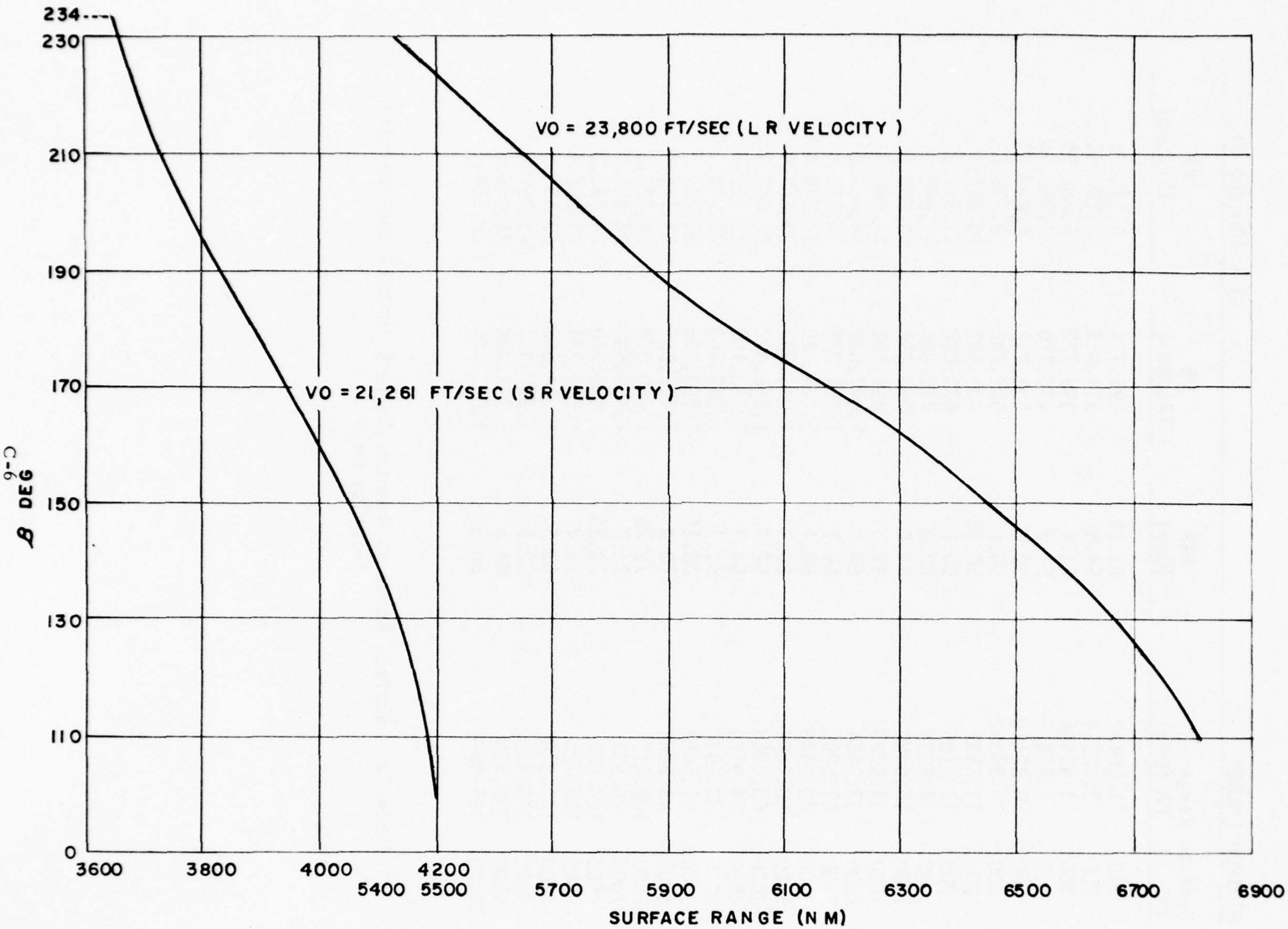


Figure 14. SURFACE RANGE VS MISSILE HEADING ANGLE (FOR S RANGE LR VELOCITIES)

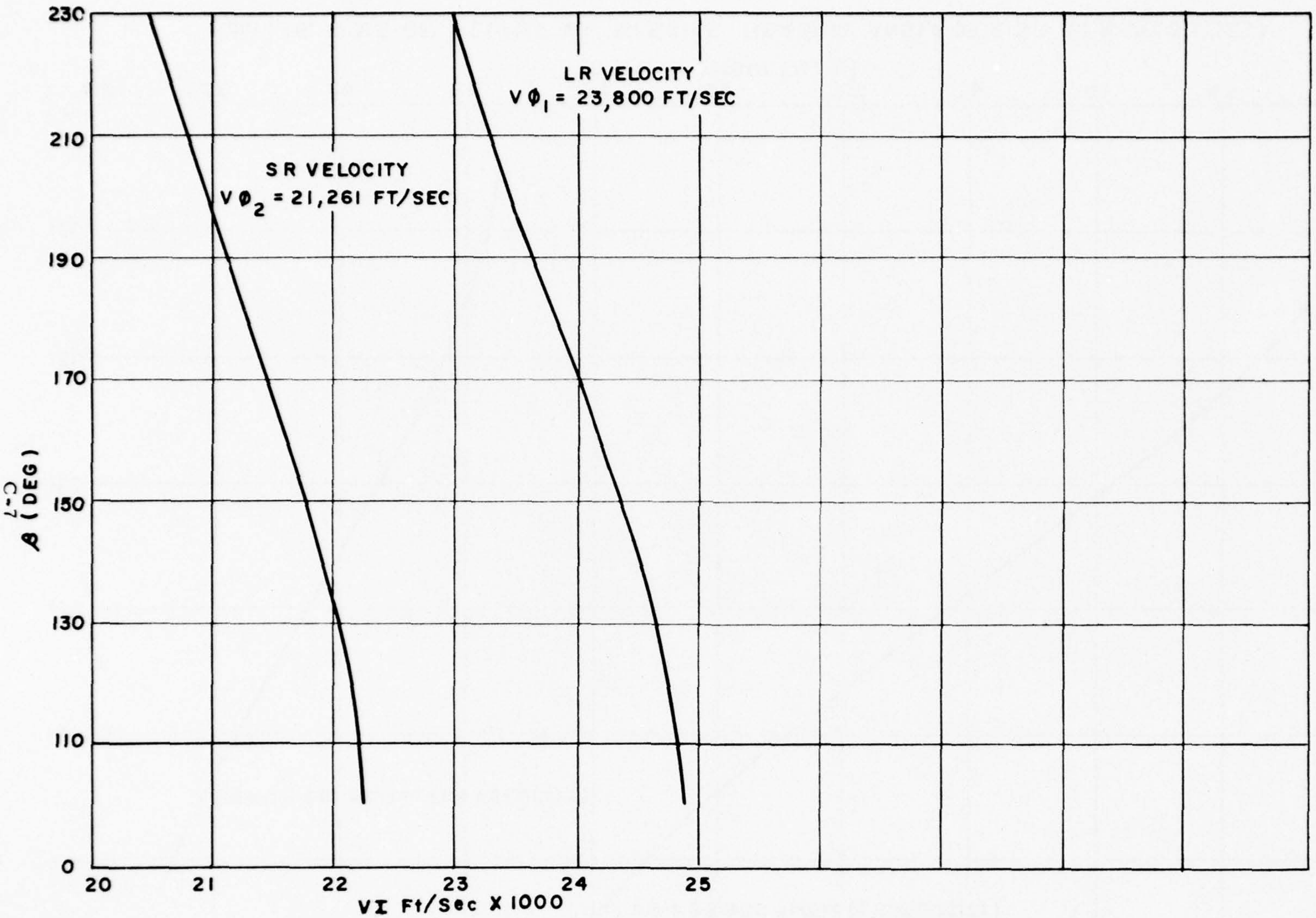


Figure 15. Inertial Velocity VS Missile Heading Angle (For Non-Inertial Burnout SR And LR Velocities

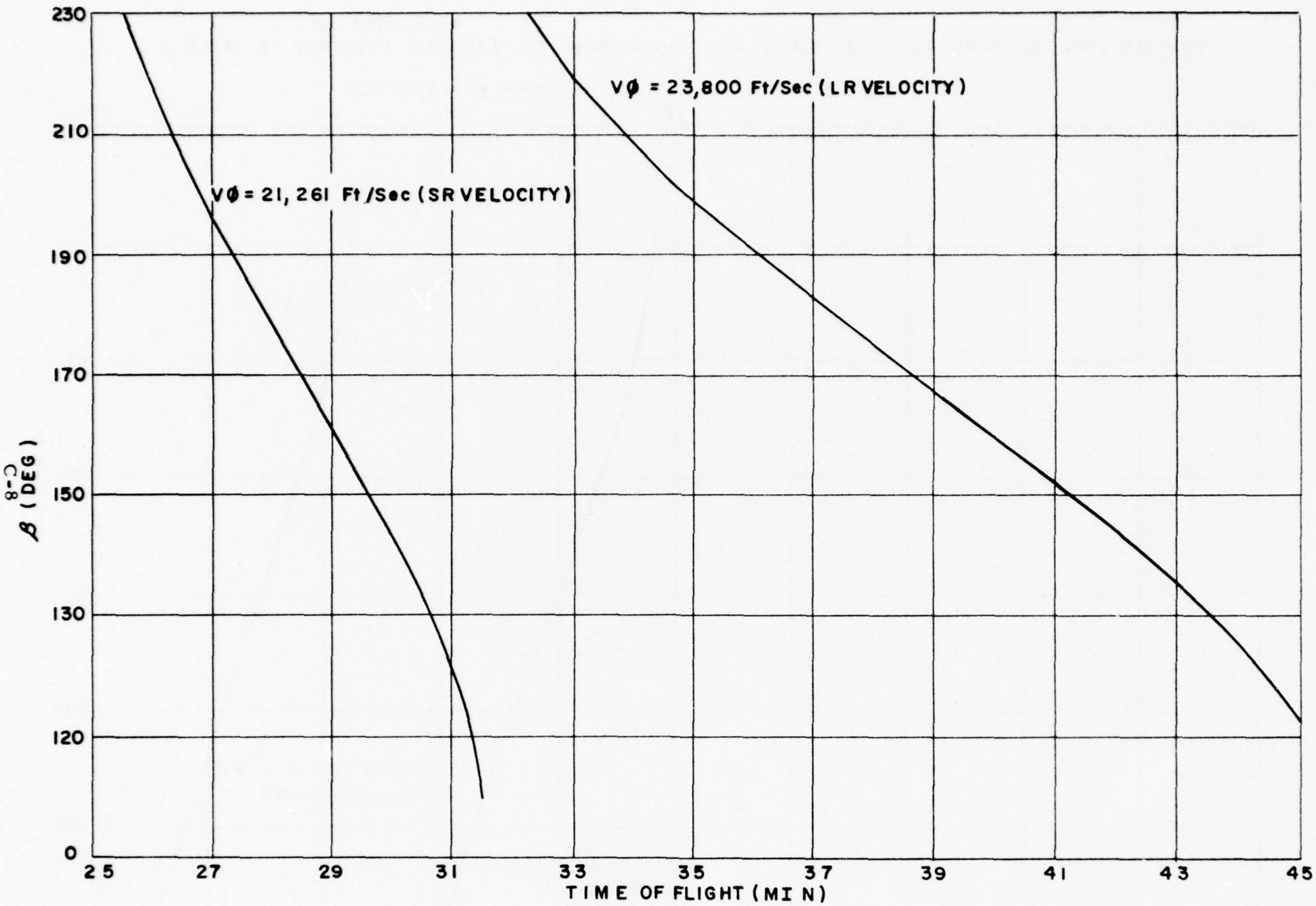


Figure 16. TIME OF FLIGHT VS MISSILE HEADING ANGLE (FOR SR & LR VELOCITIES)

```
*        PROGRAM ROTATE
      DTR = .174532925E-1
      RTD = .572957795E2
      G = 68.0
      B = 225.0
      PRINT 80,B
      T = 41.28333333
      GAM = G*DTR
      BETA = B*DTR
      VO = .142198E7
      VS = VO/60.0
      PRINT 110,VS
      W = .4375269048E-2
      THEO =T*DTR
      HX = 0.0
      PRINT 90,G,HX
      PRINT 100,T
      RE = 2.092564E7
      R = RE+HX
      SG = SIN(GAM)
      CG = COS(GAM)
      SB = SIN(BETA)
      CB = COS(BETA)
      CT = COS(THEO)
      DNOM = R*CT
      FLDO = VO*SG*SB/DNOM-W
      WF = W/FLDO
      F = (1.0-WF)**2
      FAC = CB**2+F*SB**2
      SQ = SQRT(CG**2+FAC*SG**2)
      VI = VO*SQ
      VIS = VI/60.0
      PRINT 10,VO
      PRINT 20,VI
      PRINT 40,VIS
10    FORMAT(1HO,"INITIAL VELOCITY (NONROTATING EARTH)  VO =",
&     E16.8,"FT/MIN")
20    FORMAT(1HO,"INITIAL VELOCITY (ROTATING EARTH )   VI = ",
&     E16.8,"FT/MIN")
40    FORMAT(1HO,"INITIAL VELOCITY (ROTATING EARTH)   VIS =
&     ",E16.8,"FT/SEC")
30    FORMAT(1H-,"TO OBTAIN SAME SURFACE RANGE, EARTH WAS
&     ROTATE BACKWARDS")
50    FORMAT(1H ,5(E16.8))
  60
70    FORMAT(1H ,5(E16.8))
80    FORMAT(1HO,"BETA = ",F10.6,"DEG.")
  90 FORMAT(1H ,"GAM = ",F10.6,"DEG",3X,"HX = ",E12.5,"FEET")
100   FORMAT(1H ,"LAUNCH LATITUDE = ",F14.8,"DEG")
110   FORMAT(1H ,"VOS = ",E16.8,"FT/SEC")
      STOP
      END
```

```
BETA = 225.000000DEG.
VOS =    0.23699667E+05FT/SEC
GAM =  68.000000DEG    HX =  0.                FEET
LAUNCH LATITUDE =     41.28333330DEG

INITIAL VELOCITY (NONROTATING EARTH)  VO =  0.14219800E+07FT/MIN

INITIAL VELOCITY (ROTATING EARTH )   VI =   0.14647855E+07FT/MIN

INITIAL VELOCITY (ROTATING EARTH)   VIS =        0.24413092E+05FT/SEC
```

B. Initial Missile Velocity Program

Given the missile surface range and altitude at burnout, the earth's central angle is computed by program VEL. The inertial velocity of the missile at burnout is computed as a function of reentry angle over a selected range of reentry angles. Plotting the inertial velocity, VO, as a function of the reentry angle, Y, enables one to pick VO and Y for the minimum energy trajectory. That is, the smallest value of VO is picked that will propel the missile the desired surface range. The equations for this computer program were developed by Mr. George A. Ellis of RADC/OCD.

Figure 17 shows the geometry of the situation. The following terminology is used in conjunction with Figure 17.

Y = missile reentry angle measured from the vertical

r' = geocentric range to missile at burnout - R + h

h = missile altitude at burnout

CA = missile surface range from burnout - i.e. earth's central angle

r = geocentric range to missile at time t

v = missile velocity at burnout

R = earth radius

μ = earth's gravitational constant

* See Volume I, Part 2, Appendix E

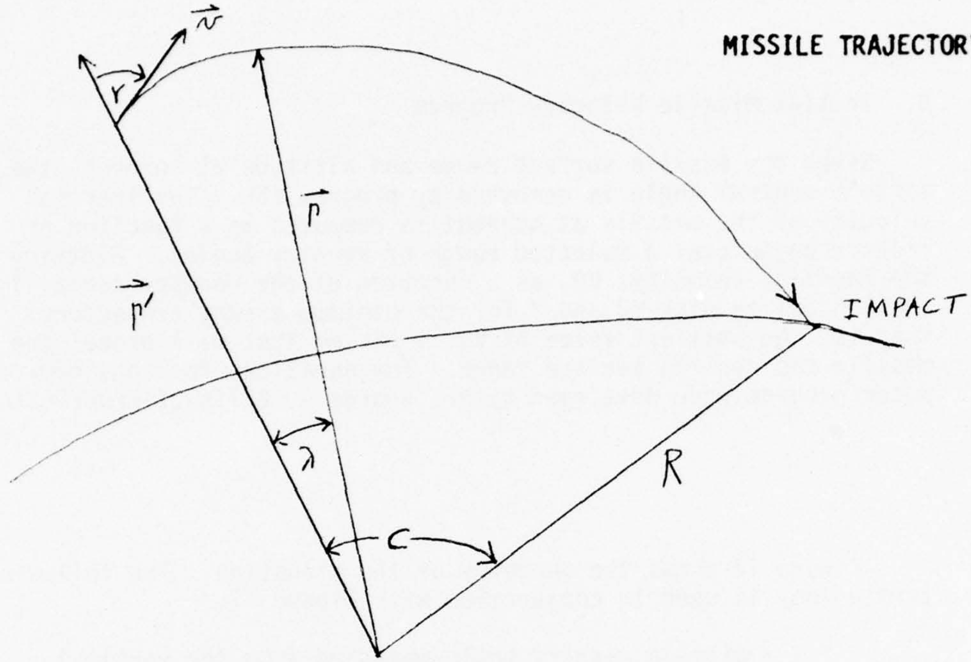


Figure 17 Missile Geometry

Thus the velocity relative to burnout is

$$v^2 = \frac{\mu}{r'} \frac{1 - \cos C}{[(r'/R)\sin^2\gamma - \sin\gamma \sin(\gamma - C)]} \tag{49}$$

where

$$r' = R + h \tag{50}$$

This is not an inertial velocity, it represents missile capability referenced to burnout at the launch point on a non-rotating earth. Depending on the missile heading angle, the rotation of the earth adds to or subtracts from v to determine the missile's inertial velocity.

Figure 18 shows the corresponding reentry angles and velocities for minimum energy trajectories for various surface ranges. The initial altitude at burnout was taken to be 400,000 feet. This is a realistic burnout altitude for surface ranges over 600 NM. For surface ranges, less than 600 NM. a realistic initial altitude at burnout is 300,000 feet.

Equation 49 has been programmed for the RADC GE 645 time sharing system by Mr. Windsor S. Thomas, RADC/OCSP.

The table delineates the inputs required for computer program VEL.

INPUTS

Program Symbol	Units	Math Symbol	Meaning
H	Feet	h	Missile altitude at burnout
K5			Number of Surface Range to be run
S(I)	NM	S	Missile surface range

Table 15 Inputs to Initial Missile Velocity Program

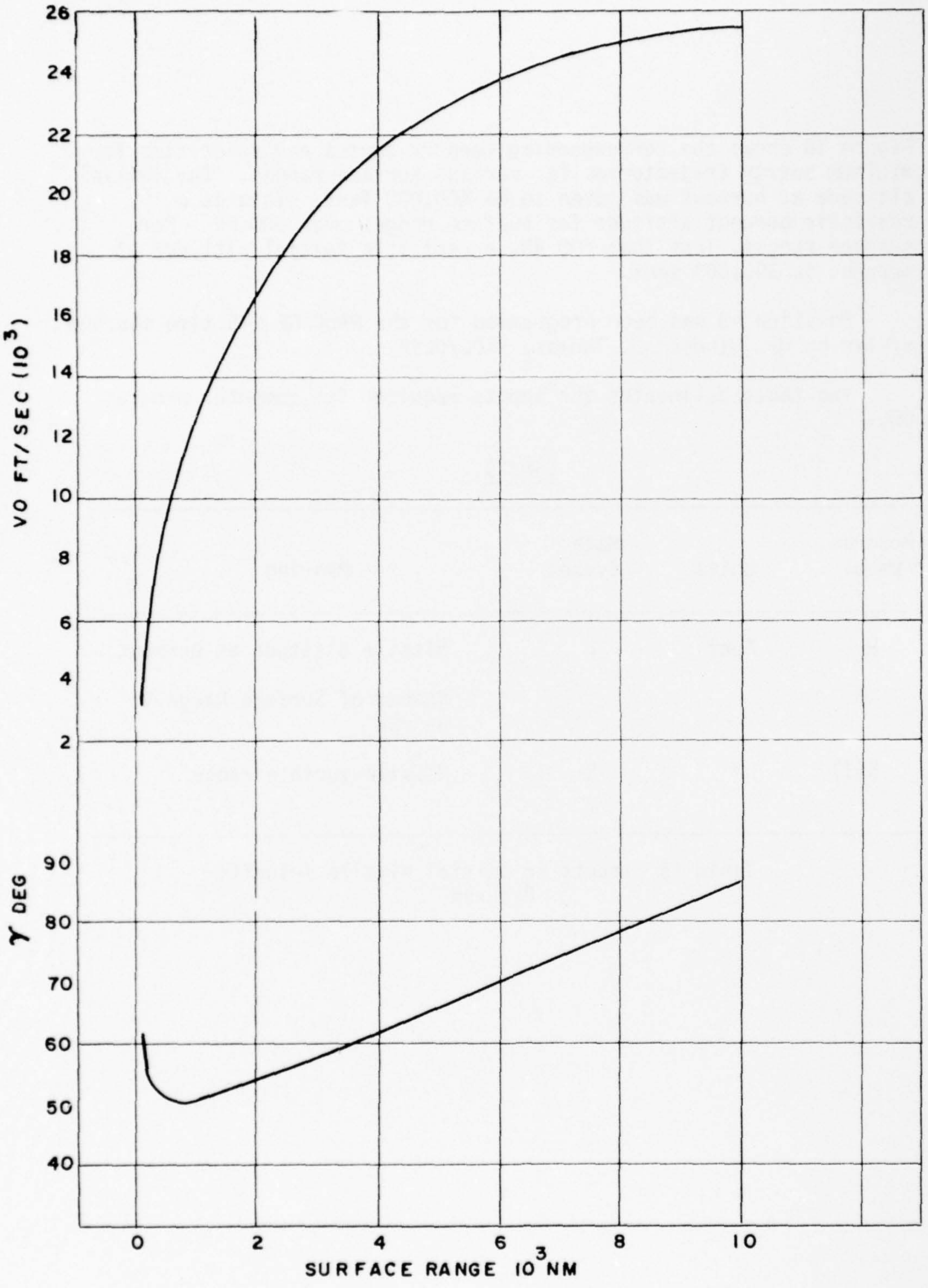


Figure 18. SURFACE RANGE VS RE-ENTRY ANGLE AND NON-INERTIAL INITIAL VELOCITY

```
00010  REM                PROGRAM VEL
00020 DIM S(10),A(10),C(10)
00030   READ H
00040    LET K1 = 6.08028E3
00050    PRINT "CALCULATION OF INITIAL VEL. OF MISSILE USING SPHERICAL"
00060   LET R2 = 2.092564E7
00070   LET R1 = R2+H
00080    PRINT"EARTH MODEL OF RADIUS =";R2
00090  READ K5
00100  FOR I = 1 TO K5
00110    READ S(I)
00120    LET R = .017453293
00130    PRINT
00140    PRINT
00150 PRINT "SURFACE RANGE = ";S(I);"N.M."
00160 PRINT "INITIAL LAUNCH ALTITUDE   HX = ";H;"   FEET"
00170    PRINT "LAUNCH POINT =";R1;"FEET"
00180    LET G1 = 1.407639E16
00190    LET A(I) = S(I)*K1/R2
00200    LET A1=A(I)/R
00210  PRINT"CENTRAL ANGLE      CA =";A1;"DEGREES"
00220  PRINT "RE-ENTRY","INITIAL VEL.","INITIAL VEL.","INITIAL VEL."
00230  PRINT "ANGLE (DEG.)","(FEET/MIN.)","(FEET/SEC.)","(N.M./SEC.)"
00240  PRINT "GAM"
00250 FOR B = 80 TO 81 STEP .1
00260    LET B1 = B*R
00270    LET X = COS(A(I))
00280    LET N=1-X
00290    LET Y = SIN(B1)
00300    LET C(I) = A(I)-B1
00310    LET Z = SIN(C(I))
00320    LET U = R1/R2
00330    LET V=(U*Y+Z)*Y
00340    LET W = G1/R1
00350    LET W1 = (W*N)/V
00360  LET W2 = SQR(W1)
00370  LET W3 = W2/K1
00380  PRINT B,W2*60,W2,W3
00390    NEXT B
00400  NEXT I
00420  REM      INPUTS
00430  REM H = INITIAL ALTITUDE IN FEET OBTAINED FROM ICBM DATA
00440 DATA 4E5
00460  REM K5 = NUMBER OF SURFACE RANGES TO BE RUN - K5 > 1
00470 DATA 1
00490  REM S(I) = SURFACE RANGE IN N.M.
00500 DATA 8500
00530    END
```

```
READY
$BASIC

            06/10/69        13:39

CALCULATION OF INITIAL VEL. OF MISSILE USING SPHERICAL
EARTH MODEL OF RADIUS = 20925640


SURFACE RANGE =  8500 N.M.
INITIAL LAUNCH ALTITUDE   HX =  400000      FEET
LAUNCH POINT = 21325640   FEET
CENTRAL ANGLE      CA =  141.510   DEGREES
RE-ENTRY          INITIAL VEL.    INITIAL VEL.    INITIAL VEL.
ANGLE (DEG.)      (FEET/MIN.)     (FEET/SEC.)     (N.M./SEC.)
GAM
 80                1511611.        25193.5         4.14348
  80.1             1511591.        25193.2         4.14342
  80.2             1511575.        25192.9         4.14338
  80.3             1511565.        25192.7         4.14335
  80.4             1511559.        25192.7         4.14334
  80.5000          1511558.        25192.6         4.14333
  80.6000          1511562.        25192.7         4.14334
  80.7000          1511570.        25192.8         4.14337
  80.8000          1511583.        25193.1         4.14340
  80.9000          1511601.        25193.4         4.14345
  81.0000          1511624.        25193.7         4.14351
```

APPENDIX D

Radar Line-of-Sight Limitations

1. Derivation of equations utilized

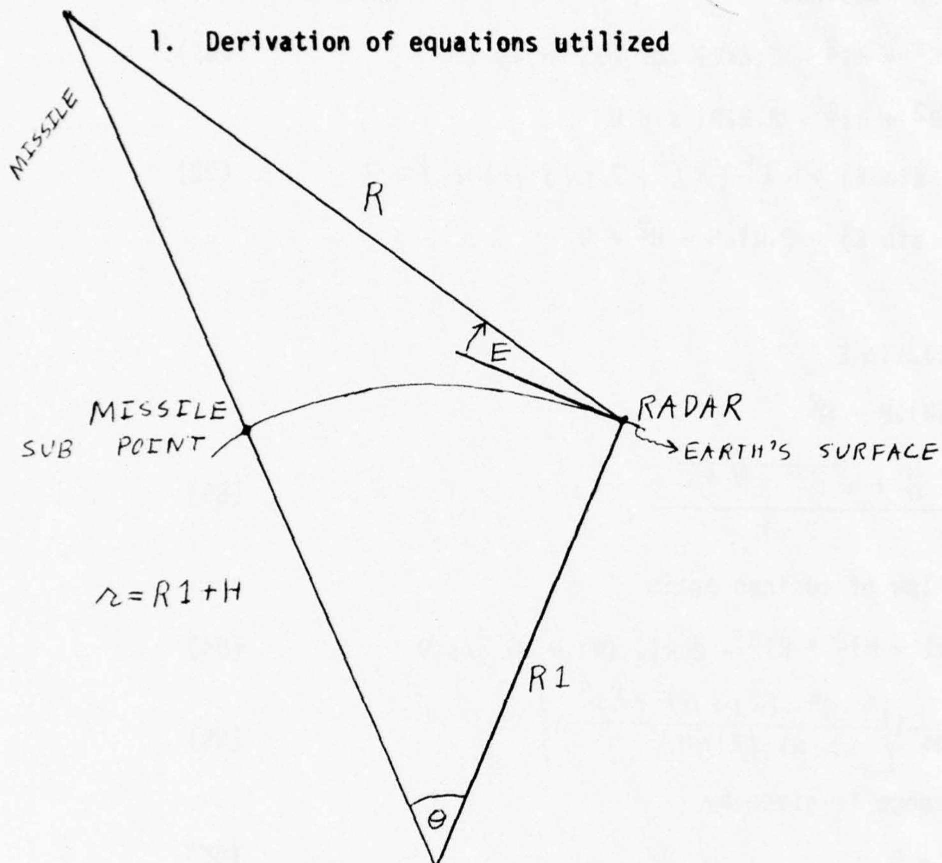


Figure 19 Missile Radar Geometry

Where R1 = earth radius = 3440 NM

θ = earth central angle from radar to missile

r = geocentric distance to the missile

S = surface range from radar to missile sub-point

R = radar slant range

E = radar elevation angle

1NM = 60 degrees = 6080 feet

Using the law of cosines

$$(R1 + H)^2 = R^2 + R1^2 - 2 \cdot R \cdot R1 \cos (90° + E) \tag{51}$$

$$(R1 + H)^2 = R^2 + R1^2 + 2 \cdot R \cdot R1 \sin E$$

$$R^2 + R\,(2 \cdot R1 \sin E) + \cancel{R1^2} - (\cancel{R1^2} + 2 \cdot R1 \cdot H + H^2) = 0 \tag{52}$$

$$R^2 + R\,(2 \cdot R1 \sin E) - 2 \cdot R1 \cdot H - H^2 = 0$$

$$A = 1$$

$$B = 2 \cdot R1 \cdot \sin E$$

$$C = -2 \cdot R1 \cdot H - H^2$$

$$R = \frac{-B + \sqrt{B^2 - 4 \cdot A \cdot C}}{2 \cdot A} \tag{53}$$

Applying the law of cosines again

$$R^2 = (R1 + H)^2 + R1^2 - 2 \cdot R1 \cdot (R1 + H) \cos \theta \tag{54}$$

$$\theta = \cos^{-1}\left[\frac{-R^2 + (R1 + H)^2 + R1^2}{2 \cdot R1 \cdot (R1 + H)}\right] \tag{55}$$

The surface range is given by

$$S = R1 \cdot \theta \tag{56}$$

2. The attached computer program reads in 12 values of the elevation angle E(M) (in degrees) from data cards. Next 9 values of altitude H1(N) (in feet) are read into the computer via data cards.

3. The output of the computer program is such that each page contains 1 elevation angle for 9 altitudes. The slant range (R in NM), surface range (S in NM), earth angle (θ = T in degrees) and cos (T = θ) (in degrees) are outputs for each altitude.

4. Printouts of the computer program and a set of plotted curves are attached.

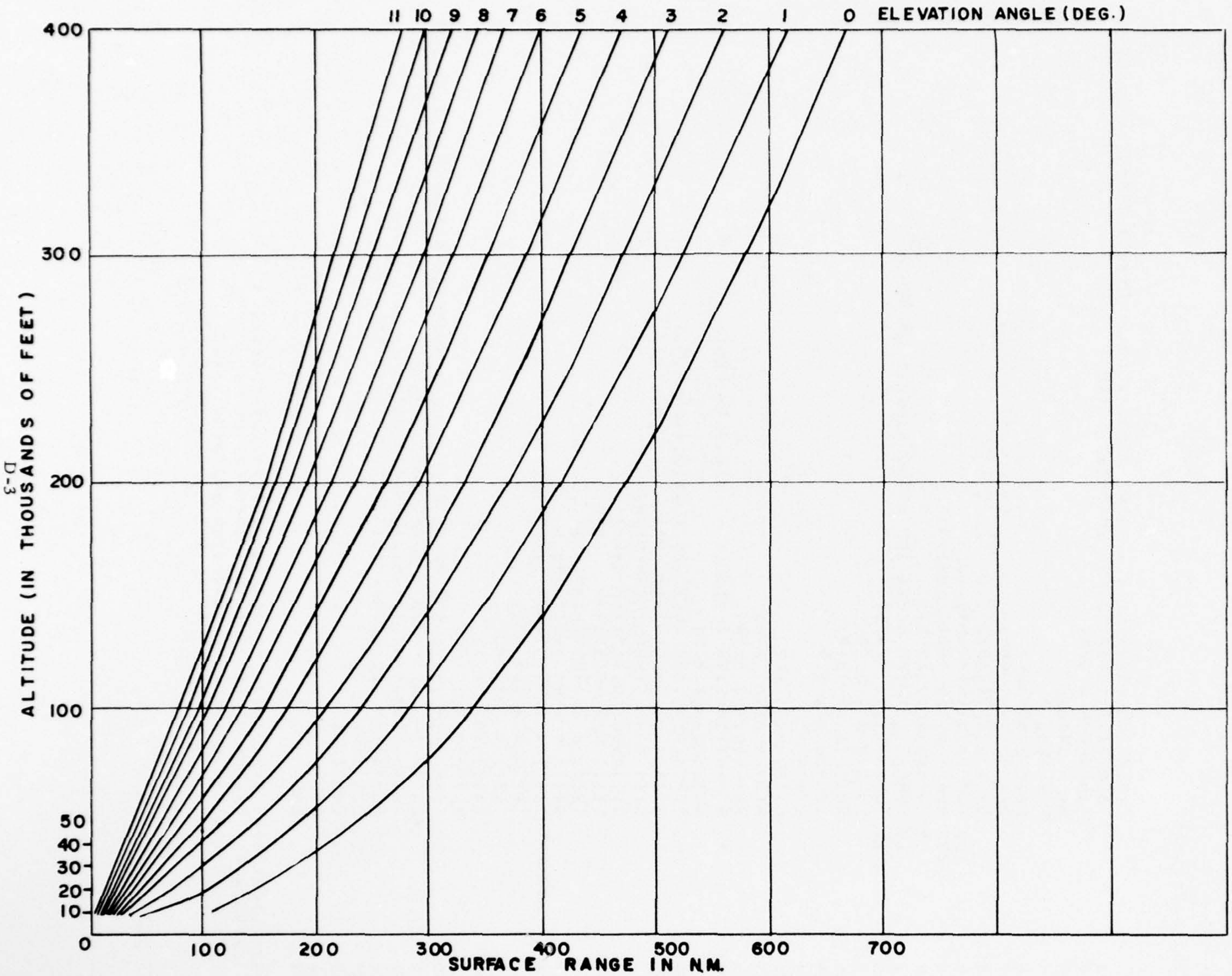


FIGURE 20. RADAR LINE-OF- SITE LIMITATIONS

```
      DIMENSION E(20),E1(20),H(20),B(400),C(400),Q(400),T1(400),T2(400),
     1T3(400),T4(400),T5(400),R4(400),S4(400)
      DIMENSION H1(20)
      R1 = 3440.0
      F = 6080.0
      F2 = 1.6447E-4
      D = 57.295779513
      D2 = 0.017453293
  100 READ(5,5)(E(M),M=1,12)
  200 READ (5,15) (H1(N),N=1,9)
    5 FORMAT(6F5.1/6F5.1)
   10 FORMAT(1H1,18H ELEVATION ANGLE =,F10.4,5H DEG.)
   15 FORMAT(5E12.4/4E12.4)
      DO 300 M = 1,12
      WRITE(6,10) E(M)
      DO 400 N = 1,9
      I = N
      E1(M)=E(M) *D2
      H(N) = H1(N) * F2
      WRITE(6,40) H1(N)
   40 FORMAT(1H0,12H ALTITUDE = ,E12.4,5H FEET)
      WRITE(6,50) H(N)
   50 FORMAT(1H ,12H ALTITUDE = ,E12.4,5H N.M.)
      B(I) =  2.0*R1*SIN(E1(M))
      C(I) = -2.0*R1*H(N)-H(N)**2
      Q(I)=SQRT(B(I)**2-4.0*C(I) )
      T1(I) =(R1+H(N))**2 +R1**2
      T2(I) = 2.0*R1*(R1+H(N))
      R4(I) = (-B(I)+Q(I))*0.5
      T3(I) = (-R4(I)**2+T1(I))/T2(I)
      T4(I) = ARCOS(T3(I))
      T5(I) = T4(I)*D
      S4(I) =R1*T4(I)
      WRITE(6,20)
   20 FORMAT(1H0,18HSLANT RANGE (N.M.),3X,20HSURFACE RANGE (N.M.),3X,19H
     *EARTH ANGLE T (DEG),3X,6HCOS(T))
      WRITE (6,30) R4(I),S4(I),T5(I),T3(I)
   30 FORMAT(5X,F10.3,14X,F10,3,12X,F10.3,8X,F10.8)
  400 CONTINUE
  300 CONTINUE
      STOP
      END
```

```
<><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
  22593 WORDS OF MEMORY USED BY THIS COMPILATION
<><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><><>
```

```
ELEVATION ANGLE =      0.      DEG.

ALT     IE =   0.1000E 05 FEET
ALT.  .UDE =   0.1645E 01 N.M.

LANT RANGE (N.M.)     SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      106.387                   106.353                   1.771            0.99952212

ALTITUDE =   0.2000E 05 FEET
ALTITUDE =   0.3289E 01 N.M.

LANT RANGE (N.M.)     SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      150.472                   150.376                   2.505            0.99904470

ALTITUDE =   0.3000E 05 FEET
ALTITUDE =   0.4934E 01 N.M.

LANT RANGE (N.M.)     SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      184.312                   184.136                   3.067            0.99856773

ALTITUDE =   0.4000E 05 FEET
ALTITUDE =   0.6579E 01 N.M.

LANT RANGE (N.M.)     SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      212.851                   212.580                   3.541            0.99809121

ALTITUDE =   0.5000E 05 FEET
AL    IDE =   0.8224E 01 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      238.003                   237.624                   3.958            0.99761514

ALTITUDE =   0.1000E 06 FEET
ALTITUDE =   0.1645E 02 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      335.788                   335.718                   5.592            0.99524164

ALTITUDE =   0.2000E 06 FEET
ALTITUDE =   0.3289E 02 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      475.857                   473.637                   7.892            0.99052836

ALTITUDE =   0.3000E 06 FEET
ALTITUDE =   0.4934E 02 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      584.723                   579.187                   9.647            0.98585951

ALTITUDE =   0.4000E 06 FEET
ALTITUDE =   0.6579E 02 N.M.

SL    RANGE (N.M.)    SURFACE RANGE (N.M.)     EARTH ANGLE T (DEG)     COS(T)
      675.980                   667.476                  11.117            0.98123446
```

ELEVATION ANGLE = 1.0000 DEG.

ALTITUDE = 0.1000E 05 FEET
ALTITUDE = 0.1645E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
62.122	62.085	1.034	0.99983714

ALTITUDE = 0.2000E 05 FEET
ALTITUDE = 0.3289E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
101.971	101.872	1.697	0.99956154

ALTITUDE = 0.3000E 05 FEET
ALTITUDE = 0.4934E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
133.807	133.628	2.226	0.99924561

ALTITUDE = 0.4000E 05 FEET
ALTITUDE = 0.6579E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
161.119	160.646	2.679	0.99890707

ALTITUDE = 0.5000E 05 FEET
ALTITUDE = 0.8224E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
185.422	185.041	3.082	0.99855361

ALTITUDE = 0.1000E 06 FEET
ALTITUDE = 0.1645E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
282.061	280.988	4.680	0.99666584

ALTITUDE = 0.2000E 06 FEET
ALTITUDE = 0.3289E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
420.585	417.565	6.955	0.99264193

ALTITUDE = 0.3000E 06 FEET
ALTITUDE = 0.4934E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
527.760	522.222	8.698	0.98849917

ALTITUDE = 0.4000E 06 FEET
ALTITUDE = 0.6579E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
618.605	610.097	10.162	0.98431398

```
ELEVATION ANGLE =    2.0000 DEG,

AL     UE =   0.1000E 05 FEET
ALT.  UDE =   0.1645E 01 N.M.

LANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
       40.355                40.313                 0.671        0.99993134

ALTITUDE =   0.2000E 05 FEET
ALTITUDE =   0.3289E 01 N.M.

LANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
       72.442                72.333                 1.205        0.99977894

ALTITUDE =   0.3000E 05 FEET
ALTITUDE =   0.4934E 01 N.M.

LANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
       99.909                99.719                 1.661        0.99957988

ALTITUDE =   0.4000E 05 FEET
ALTITUDE =   0.6579E 01 N.M.

LANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      124.319               124.034                 2.066        0.99935004

ALTITUDE =   0.5000E 05 FEET
AL    UDE =   0.8224E 01 N.M.

SLAN  RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      146.513               146.119                 2.434        0.99909801

ALTITUDE =   0.1000E 06 FEET
ALTITUDE =   0.1645E 02 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      237.491               236.403                 3.937        0.99763958

ALTITUDE =   0.2000E 06 FEET
ALTITUDE =   0.3289E 02 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      371.683               368.644                 6.140        0.99426345

ALTITUDE =   0.3000E 06 FEET
ALTITUDE =   0.4934E 02 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      475.866               471.310                 7.850        0.99062900

ALTITUDE =   0.4000E 06 FEET
ALTITUDE =   0.6579E 02 N.M.

SL    RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      565.504               557.978                 9.294        0.98687391
```

ELEVATION ANGLE =   3.0000 DEG.

AL   IDE =   0.1000E 05 FEET
AL   UDE =   0.1645E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
29.084	29.029	0.484	0.99996439

ALTITUDE =   0.2000E 05 FEET
ALTITUDE =   0.3289E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
54.602	54.476	0.907	0.99987461

ALTITUDE =   0.3000E 05 FEET
ALTITUDE =   0.4934E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
77.615	77.403	1.289	0.99974687

ALTITUDE =   0.4000E 05 FEET
ALTITUDE =   0.6579E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
98.744	98.435	1.640	0.99959063

ALTITUDE =   0.5000E 05 FEET
AL   UDE =   0.8224E 01 N.M.

SLA RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
118.390	117.970	1.965	0.99941203

ALTITUDE =   0.1000E 06 FEET
ALTITUDE =   0.1645E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
201.853	200.731	3.343	0.99829800

ALTITUDE =   0.2000E 06 FEET
ALTITUDE =   0.3289E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
329.676	326.596	5.440	0.99549652

ALTITUDE =   0.3000E 06 FEET
ALTITUDE =   0.4934E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
431.776	426.176	7.098	0.99233563

ALTITUDE =   0.4000E 06 FEET
ALTITUDE =   0.6579E 02 N.M.

SL RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
519.509	510.938	8.510	0.98898991

ELEVATION ANGLE = 4.0000 DEG.

ALTITUDE = 0.1000E 05 FEET
ALTITUDE = 0.1645E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
22.526	22.461	0.374	0.99997868

ALTITUDE = 0.2000E 05 FEET
ALTITUDE = 0.3289E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
43.275	43.128	0.718	0.99992141

ALTITUDE = 0.3000E 05 FEET
ALTITUDE = 0.4934E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
62.615	62.374	1.039	0.99983562

ALTITUDE = 0.4000E 05 FEET
ALTITUDE = 0.6579E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
80.798	80.455	1.340	0.99972651

ALTITUDE = 0.5000E 05 FEET
ALTITUDE = 0.8224E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
98.013	97.554	1.625	0.99959791

ALTITUDE = 0.1000E 06 FEET
ALTITUDE = 0.1645E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
173.569	172.394	2.871	0.99874453

ALTITUDE = 0.2000E 06 FEET
ALTITUDE = 0.3289E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
293.868	290.721	4.842	0.99643099

ALTITUDE = 0.3000E 06 FEET
ALTITUDE = 0.4934E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
392.084	386.410	6.436	0.99369778

ALTITUDE = 0.4000E 06 FEET
ALTITUDE = 0.6579E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
477.346	468.696	7.806	0.99073246

```
ELEVATION ANGLE =    5.0000 DEG.

 ALTITUDE =    0.1000E 05 FEET
 ALTITUDE =    0.1645E 01 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      18.316                  18.236                     0.304    0.99998595

 ALTITUDE =    0.2000E 05 FEET
 ALTITUDE =    0.3289E 01 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      35.641                  35.470                     0.591    0.99994684

 ALTITUDE =    0.3000E 05 FEET
 ALTITUDE =    0.4934E 01 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      52.122                  51.850                     0.864    0.99988641

 ALTITUDE =    0.4000E 05 FEET
 ALTITUDE =    0.6579E 01 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      67.873                  67.490                     1.124    0.99980755

 ALTITUDE =    0.5000E 05 FEET
 ALTITUDE =    0.8224E 01 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
      82.983                  82.479                     1.374    0.99971258

 ALTITUDE =    0.1000E 06 FEET
 ALTITUDE =    0.1645E 02 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
     151.089                 149.846                     2.496    0.99905142

 ALTITUDE =    0.2000E 06 FEET
 ALTITUDE =    0.3289E 02 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
     263.462                 260.222                     4.334    0.99714021

 ALTITUDE =    0.3000E 06 FEET
 ALTITUDE =    0.4934E 02 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
     357.292                 351.510                     5.855    0.99478383

 ALTITUDE =    0.4000E 06 FEET
 ALTITUDE =    0.6579E 02 N.M.

SLANT RANGE (N.M.)   SURFACE RANGE (N.M.)   EARTH ANGLE T (DEG)   COS(T)
     439.670                 430.904                     7.177    0.99216489
```

```
ELEVATION ANGLE =    6.0000 DEG.

 AL     DE =    0.1000E 05 FEET
 AL . UDE =    0.1645E 01 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
       15.408                    15.314                    0.255        0.99999009

 ALTITUDE =    0.2000E 05 FEET
 ALTITUDE =    0.3289E 01 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
       30.215                    30.018                    0.500        0.99996193

 ALTITUDE =    0.3000E 05 FEET
 ALTITUDE =    0.4934E 01 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
       44.485                    44.178                    0.736        0.99991754

 ALTITUDE =    0.4000E 05 FEET
 ALTITUDE =    0.6579E 01 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
       58.276                    57.849                    0.964        0.99985860

 ALTITUDE =    0.5000E 05 FEET
 AL    UDE =    0.8224E 01 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
       71.632                    71.075                    1.184        0.99978656

 ALTITUDE =    0.1000E 06 FEET
 ALTITUDE =    0.1645E 02 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
      133.090                   131.764                    2.195        0.99926651

 ALTITUDE =    0.2000E 06 FEET
 ALTITUDE =    0.3289E 02 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
      237.657                   234.297                    3.902        0.99768144

 ALTITUDE =    0.3000E 06 FEET
 ALTITUDE =    0.4934E 02 N.M.

SLANT RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
      325.860                   320.938                    5.345        0.99565109

 ALTITUDE =    0.4000E 06 FEET
 ALTITUDE =    0.6579E 02 N.M.

SL     RANGE (N.M.)    SURFACE RANGE (N.M.)    EARTH ANGLE T (DEG)    COS(T)
      405.089                   397.168                    6.615        0.99334239
```

ELEVATION ANGLE = 7.0000 DEG.

AL JDE = 0.1000E 05 FEET
AL UDE = 0.1645E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
13.288	13.179	0.220	0.99999266

ALTITUDE = 0.2000E 05 FEET
ALTITUDE = 0.3289E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
26.186	25.964	0.432	0.99997152

ALTITUDE = 0.3000E 05 FEET
ALTITUDE = 0.4934E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
38.727	38.381	0.639	0.99993776

ALTITUDE = 0.4000E 05 FEET
ALTITUDE = 0.6579E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
50.939	50.464	0.841	0.99989240

ALTITUDE = 0.5000E 05 FEET
A' 'UDE = 0.8224E 01 N.M.

SLAN RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
62.848	62.234	1.037	0.99983636

ALTITUDE = 0.1000E 06 FEET
ALTITUDE = 0.1645E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
118.524	117.104	1.950	0.99942064

ALTITUDE = 0.2000E 06 FEET
ALTITUDE = 0.3289E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
215.708	212.207	3.534	0.99809790

ALTITUDE = 0.3000E 06 FEET
ALTITUDE = 0.4934E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
300.252	294.158	4.899	0.99634615

ALTITUDE = 0.4000E 06 FEET
ALTITUDE = 0.6579E 02 N.M.

SL RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
375.196	367.082	6.114	0.99431191

ELEVATION ANGLE = 8.0000 DEG,

AL[illegible]DE = 0.1000E 05 FEET
ALT[illegible]UDE = 0.1645E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
11.678	11.554	0.192	0.99999436

ALTITUDE = 0.2000E 05 FEET
ALTITUDE = 0.3289E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
23.090	22.839	0.380	0.99997796

ALTITUDE = 0.3000E 05 FEET
ALTITUDE = 0.4934E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
34.253	33.868	0.564	0.99995153

ALTITUDE = 0.4000E 05 FEET
ALTITUDE = 0.6579E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
45.164	44.660	0.744	0.99991573

ALTITUDE = 0.5000E 05 FEET
AL[illegible]UDE = 0.8224E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
55.896	55.223	0.920	0.99987115

ALTITUDE = 0.1000E 06 FEET
ALTITUDE = 0.1645E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
105.593	105.069	1.750	0.99953359

ALTITUDE = 0.2000E 06 FEET
ALTITUDE = 0.3289E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
195.966	193.304	3.220	0.99842159

ALTITUDE = 0.3000E 06 FEET
ALTITUDE = 0.4934E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
275.961	270.667	4.508	0.99690615

ALTITUDE = 0.4000E 06 FEET
ALTITUDE = 0.6579E 02 N.M.

SL[illegible] RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
349.590	340.246	5.667	0.99511252

ELEVATION ANGLE = 9.0000 DEG.

ALTITUDE = 0.1000E 05 FEET
ALTITUDE = 0.1645E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
10.415	10.277	0.171	0.99999554

ALTITUDE = 0.2000E 05 FEET
ALTITUDE = 0.3289E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
20.642	20.365	0.339	0.99998248

ALTITUDE = 0.3000E 05 FEET
ALTITUDE = 0.4934E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
30.689	30.267	0.504	0.99996129

ALTITUDE = 0.4000E 05 FEET
ALTITUDE = 0.6579E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
40.566	39.992	0.666	0.99993242

ALTITUDE = 0.5000E 05 FEET
ALTITUDE = 0.8224E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
50.282	49.548	0.825	0.99989627

ALTITUDE = 0.1000E 06 FEET
ALTITUDE = 0.1645E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
95.700	95.067	1.583	0.99961516

ALTITUDE = 0.2000E 06 FEET
ALTITUDE = 0.3289E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
180.880	177.039	2.949	0.99867[illegible]

ALTITUDE = 0.3000E 06 FEET
ALTITUDE = 0.4934E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
255.529	250.008	4.164	0.99736[illegible]

ALTITUDE = 0.4000E 06 FEET
ALTITUDE = 0.6579E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE I (DEG)	COS(I)
325.890	316.283	5.268	0.99577624

ELEVATION ANGLE = 10.0000 DEG.

ALTITUDE = 0.1000E 05 FEET
ALTITUDE = 0.1645E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
9.400	9.248	0.154	0.99999639

ALTITUDE = 0.2000E 05 FEET
ALTITUDE = 0.3289E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
18.660	18.357	0.306	0.99998576

ALTITUDE = 0.3000E 05 FEET
ALTITUDE = 0.4934E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
27.788	27.324	0.455	0.99996845

ALTITUDE = 0.4000E 05 FEET
ALTITUDE = 0.6579E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
35.789	36.162	0.602	0.99994475

ALTITUDE = 0.5000E 05 FEET
ALTITUDE = 0.8224E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
45.668	44.869	0.747	0.99991494

ALTITUDE = 0.1000E 06 FEET
ALTITUDE = 0.1645E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
83.400	86.652	1.443	0.99968276

ALTITUDE = 0.2000E 06 FEET
ALTITUDE = 0.3289E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
165.993	162.959	2.714	0.99887817

ALTITUDE = 0.3000E 06 FEET
ALTITUDE = 0.4934E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
233.549	231.779	3.860	0.99773099

ALTITUDE = 0.4000E 06 FEET
ALTITUDE = 0.6579E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
304.746	294.845	4.911	0.99632908

ELEVATION ANGLE = 11.0000 DEG.

AL IUE = 0.1000E 05 FEET
AL UDE = 0.1645E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
8.566	8.398	0.140	0.99999702

ALTITUDE = 0.2000E 05 FEET
ALTITUDE = 0.3289E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
17.027	16.692	0.278	0.99998823

ALTITUDE = 0.3000E 05 FEET
ALTITUDE = 0.4934E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
25.386	24.882	0.414	0.99997384

ALTITUDE = 0.4000E 05 FEET
ALTITUDE = 0.6579E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
33.649	32.969	0.549	0.99995407

ALTITUDE = 0.5000E 05 FEET
A' 'UDE = 0.8224E 01 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
41.818	40.953	0.682	0.99992914

ALTITUDE = 0.1000E 06 FEET
ALTITUDE = 0.1645E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
81.360	79.492	1.324	0.99973302

ALTITUDE = 0.2000E 06 FEET
ALTITUDE = 0.3289E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
154.932	150.693	2.510	0.99904067

ALTITUDE = 0.3000E 06 FEET
ALTITUDE = 0.4934E 02 N.M.

SLANT RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
222.673	215.632	3.592	0.99803601

ALTITUDE = 0.4000E 06 FEET
ALTITUDE = 0.6579E 02 N.M.

SL RANGE (N.M.)	SURFACE RANGE (N.M.)	EARTH ANGLE T (DEG)	COS(T)
285.842	275.620	4.591	0.99679194

APPENDIX E - Miscellaneous Notes

GAM is measured from the vertical in the computer program. When comparing to data in RADC-TR-71-60 note that the GAM, referred to in the data labels (P221), is measured from the horizontal. Also note that TM is defined backwards in OC-TM-71-4. RADC-TR-73-416 documents several orbital transfer maneuvers and the required inputs.